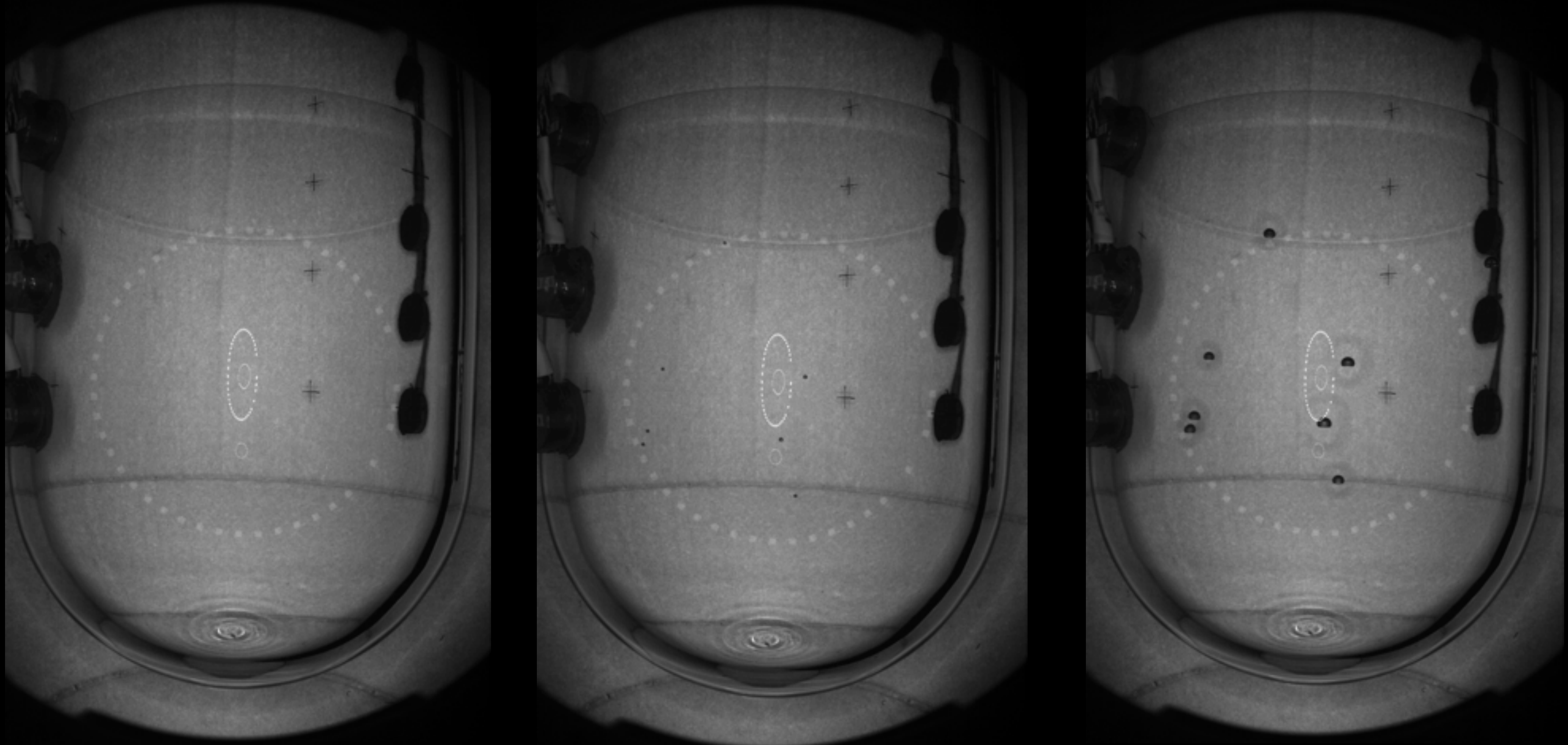


Progress on COUPP60

Hugh Lippincott, Fermilab

for the PICO/COUPP Collaboration

TAUP, Asilomar, CA

September 11, 2013

PICO
Collaboration

C. Amole, M. Besnier, G. Caria, A. Kamaha, A. Noble, T. Xie — Queen's University

M. Ardid, M. Bou-Cabo — Universitat Politècnica de València

D. Asner, J. Hall — Pacific Northwest National Laboratory

D. Baxter, C.E. Dahl, M. Jin — Northwestern University

E. Behnke, H. Borsodi, C. Harnish, O. Harris, C. Holdeman, I. Levine, E. Mann, J. Wells — Indiana University South Bend

P. Bhattacharjee, M. Das, S. Seth — Saha Institute of Nuclear Physics, Calcutta

S.J. Brice, D. Broemmelsiek, P.S. Cooper, M. Crisler, W.H. Lippincott, E. Ramberg, M.K. Ruschman, A. Sonnenschein — Fermilab

J.I. Collar, R. Neilson, A.E. Robinson — KICP, Kavli Institute for Cosmological Physics at the University of Chicago

F. Debris, M. Fines-Neuschild, C.M. Jackson, M. Lafrenière, M. Laurin, L. Lessard, J.-P. Martin, M.-C. Piro, A. Plante, O. Scallon, N. Starinski, V. Zacek — Université de Montréal

N. Dhungana, J. Farine, R. Podviyanuk, U. Wichoski — Laurentian University / Université Laurentienne

R. Filgas, S. Pospisil, I. Stekl — Czech Technical University in Prague

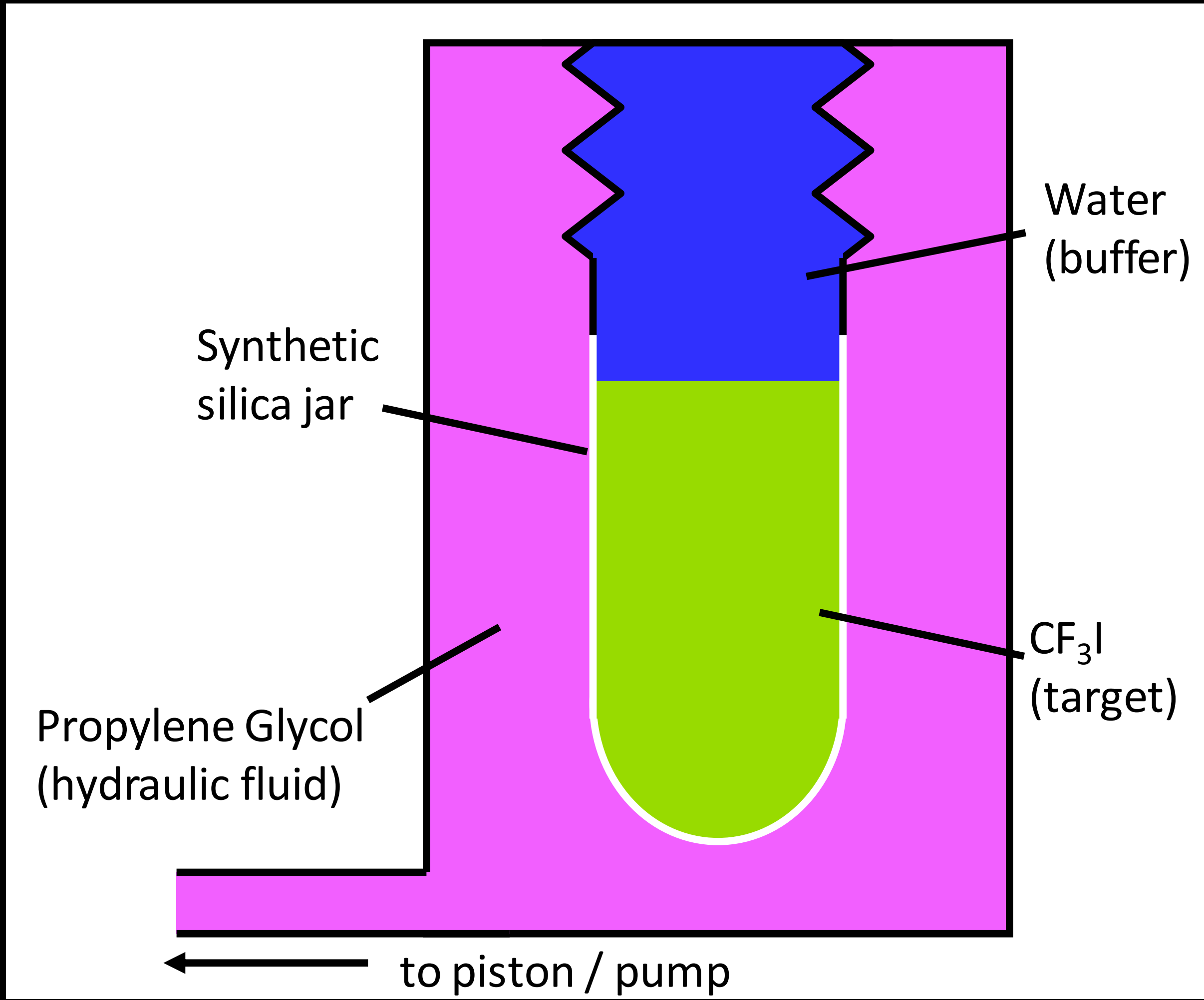
S. Gagnebin, C. Krauss, D. Marlisov, P. Mitra — University of Alberta

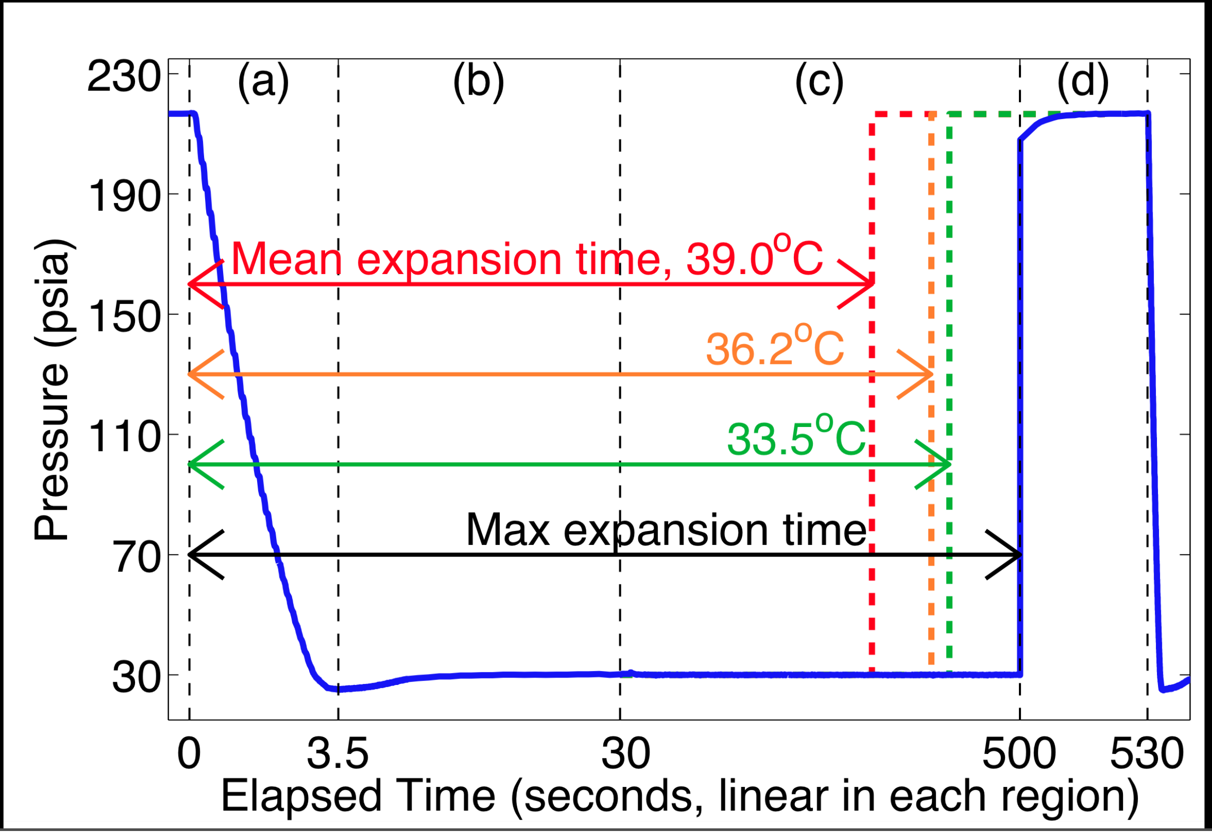
D. Maurya, S. Priya — Virginia Tech

I. Lawson, E. Vázquez Jáuregui — SNOLAB, Mining for Knowledge / Creuser pour trouver... l'excellence

PICO/COUPP fast compression bubble chamber

- Pressure expansion creates superheated fluid, CF_3I
  - I for spin-independent
  - F for spin-dependent
  - Alternatives - e.g. C_3F_8 (see talk on PICO-2L by R. Neilson, DM II)
- Particle interactions nucleate bubbles
- Cameras see bubbles
- Recompress chamber to reset

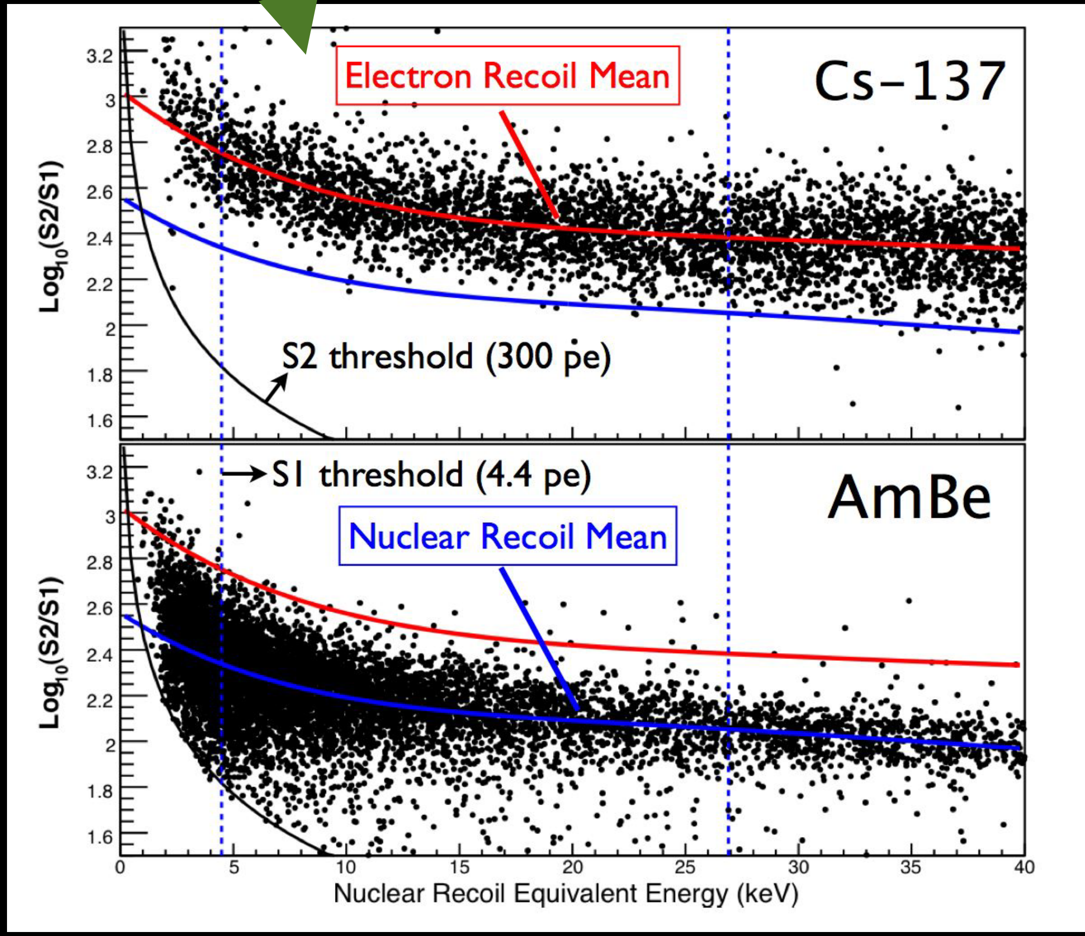




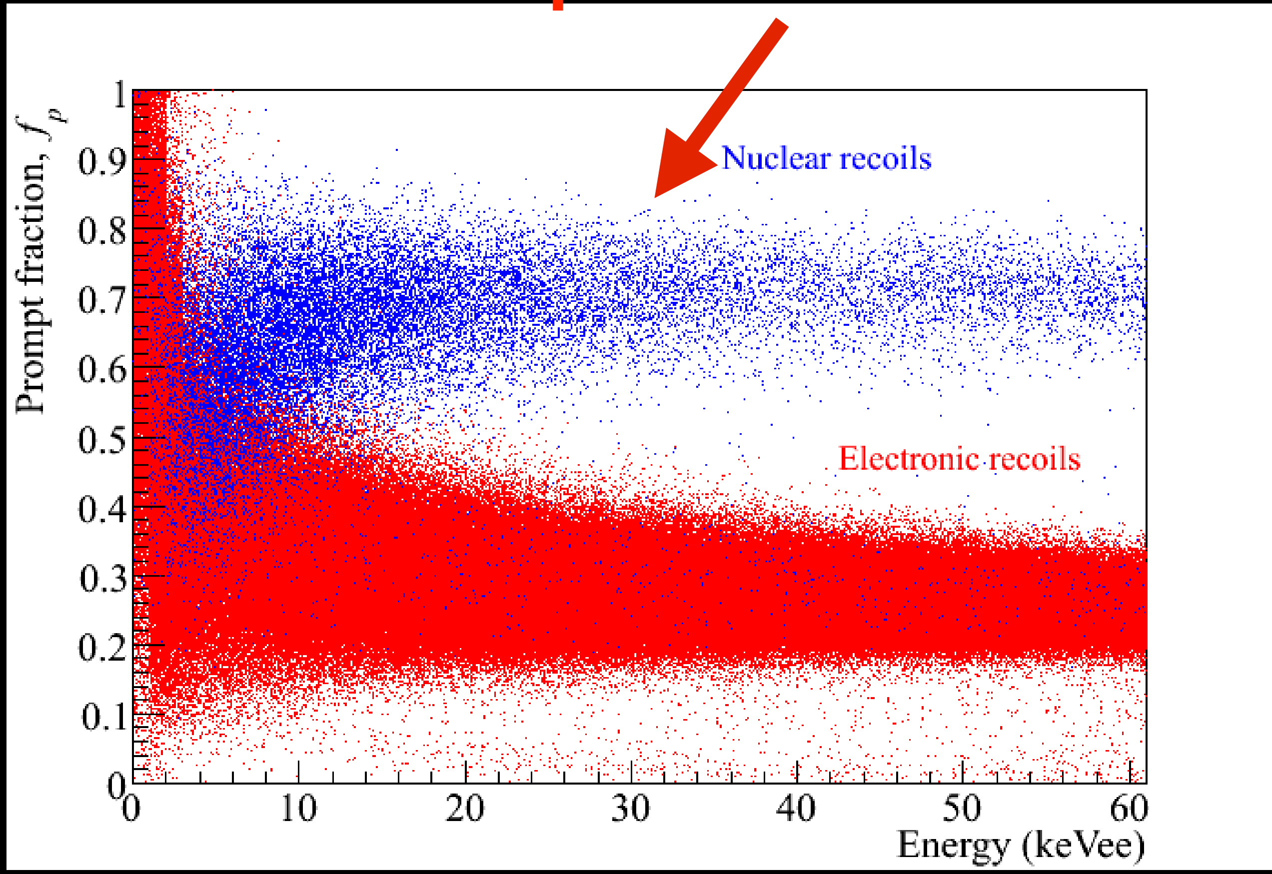
Why bubble chambers?

- A lot of effort in dark matter experiments goes into discriminating electronic recoils (gammas) vs. nuclear recoils(WIMPs)

Xenon TPCs - Charge to light

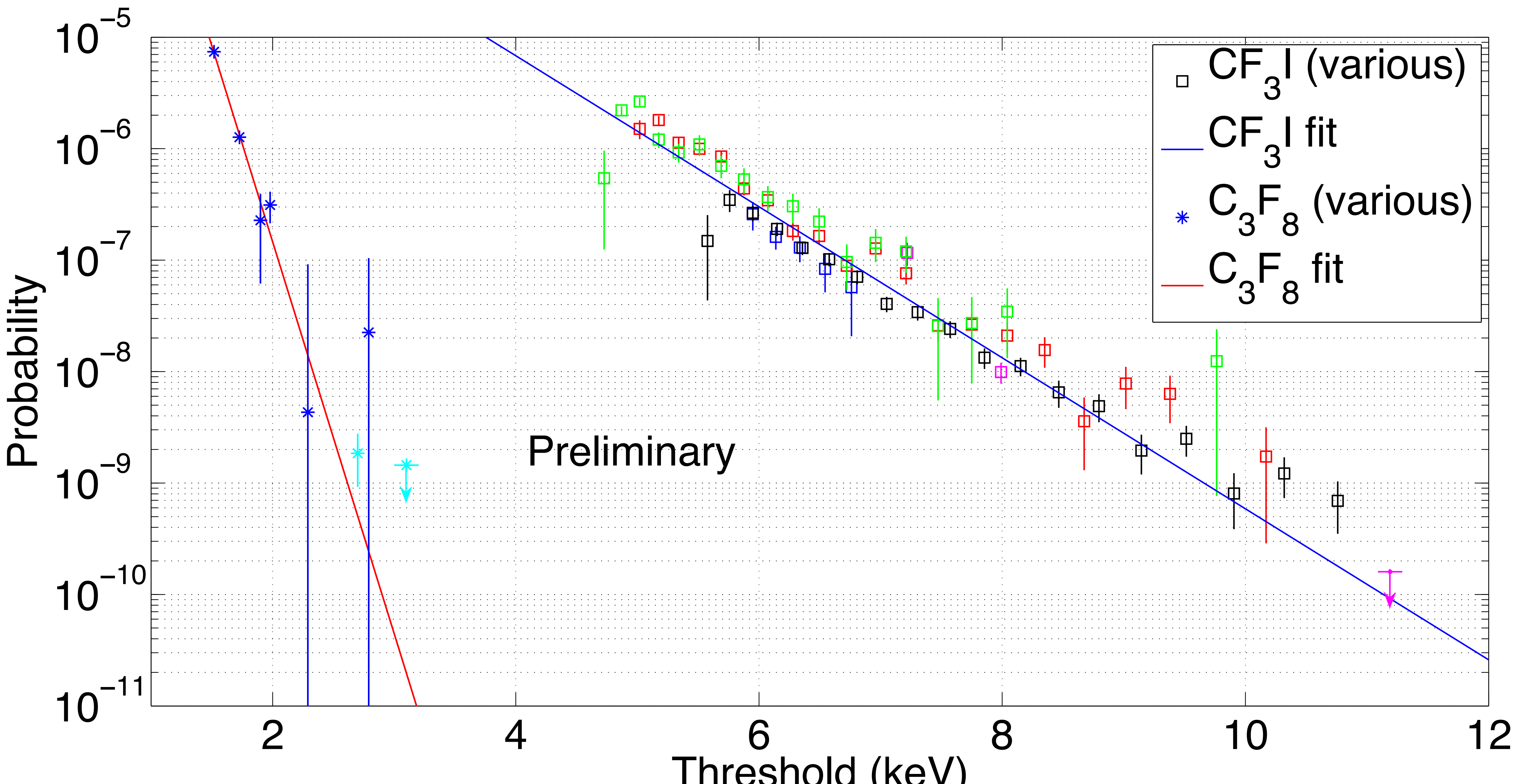


Argon - Pulse shape discrimination



Why bubble chambers?

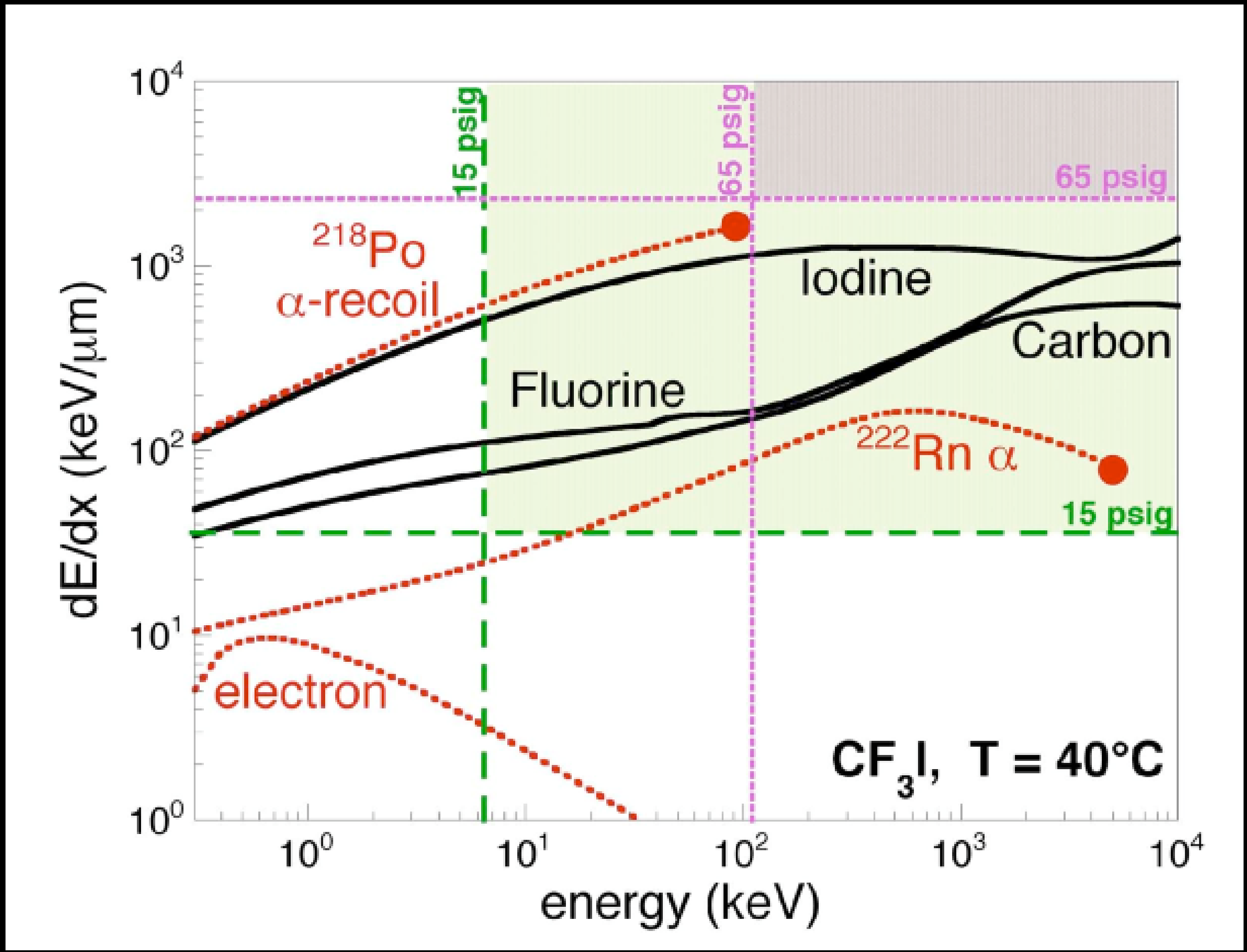
- By choosing superheat parameters appropriately (temperature and pressure), bubble chambers are blind to electronic recoils (10^{-10} or better)



Why bubble chambers?

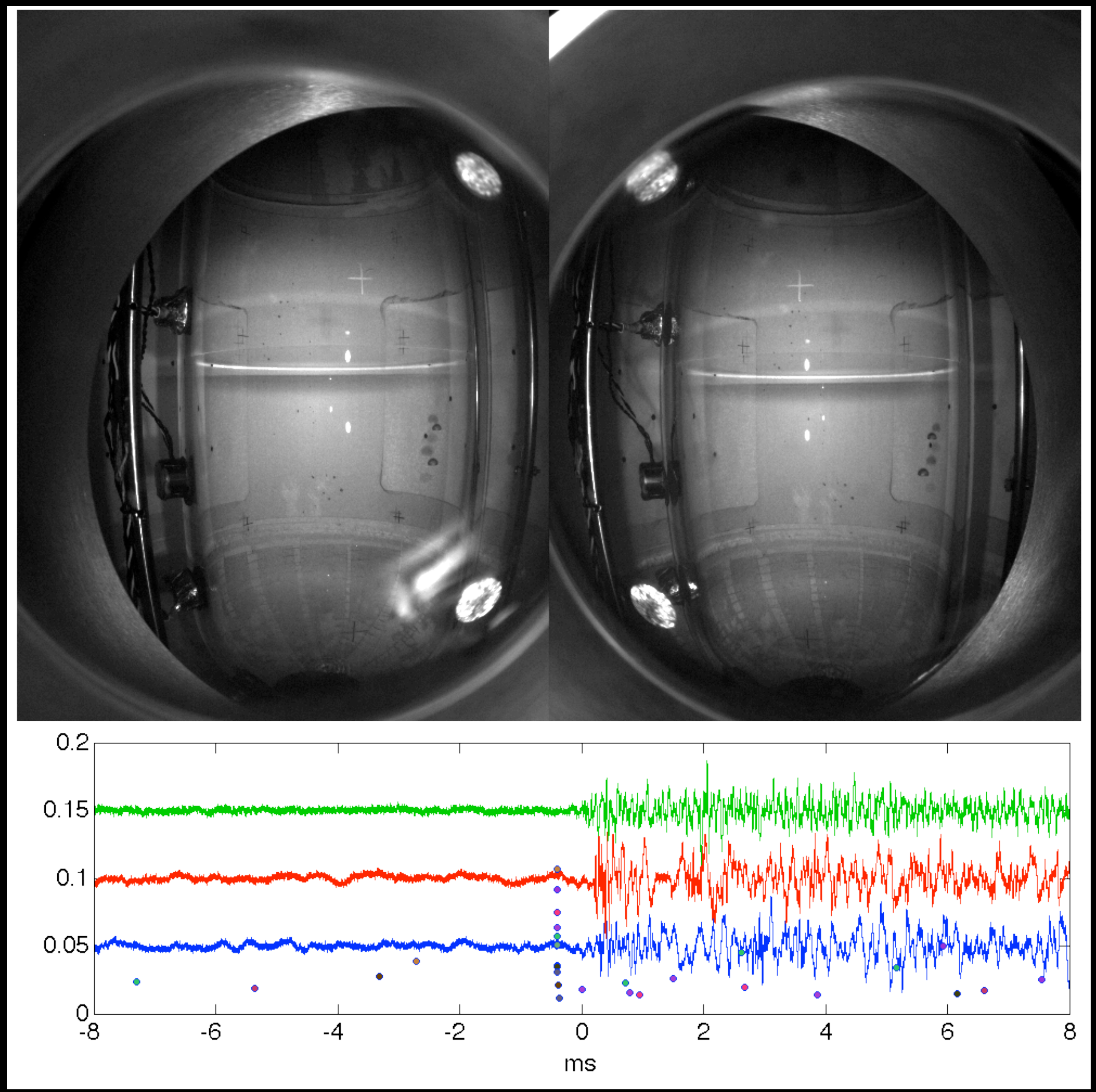
- By choosing superheat parameters appropriately (temperature and pressure), bubble chambers are blind to electronic recoils (10^{-10} or better)
- To form a bubble requires two things
  - Enough energy
  - Enough energy density - length scale must be comparable to the critical bubble size

Why bubble chambers?



Why bubble chambers?

- Easy to identify multiple scattering events → Neutron backgrounds



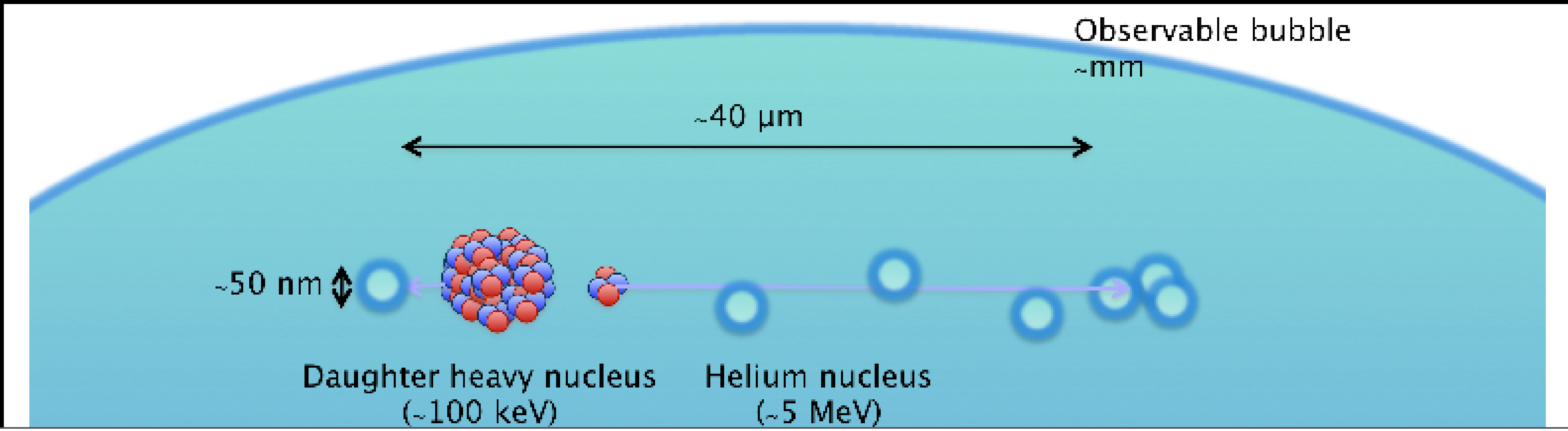
- Easy DAQ and analysis chain
    - Cameras
    - Piezos
- No PMTs, no cryogenics

Why not bubble chambers?

- Threshold detectors - no energy resolution
  - Harder to distinguish some backgrounds, less information about any potential signal
    - Alphas (several MeV) were a big concern
  - Energy threshold calibrations are hard and important
- Bubble chambers are slow - about 30 s of deadtime for every event
  - Overall rate must be low

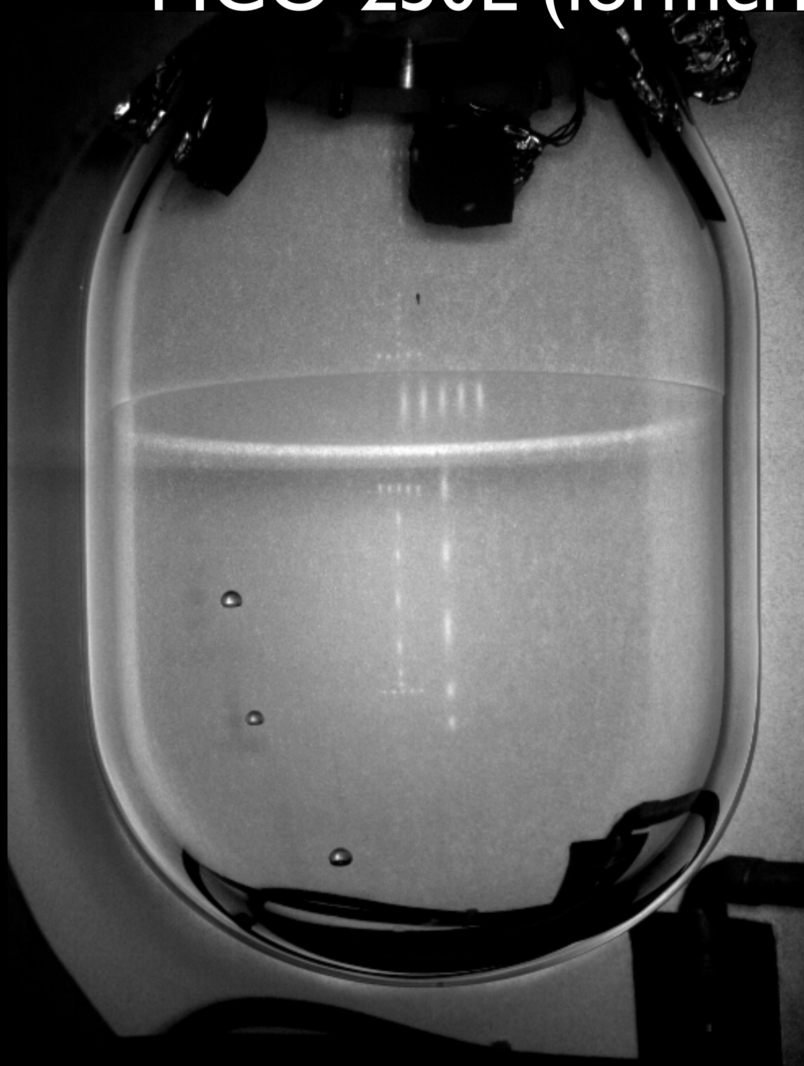
About those alphas

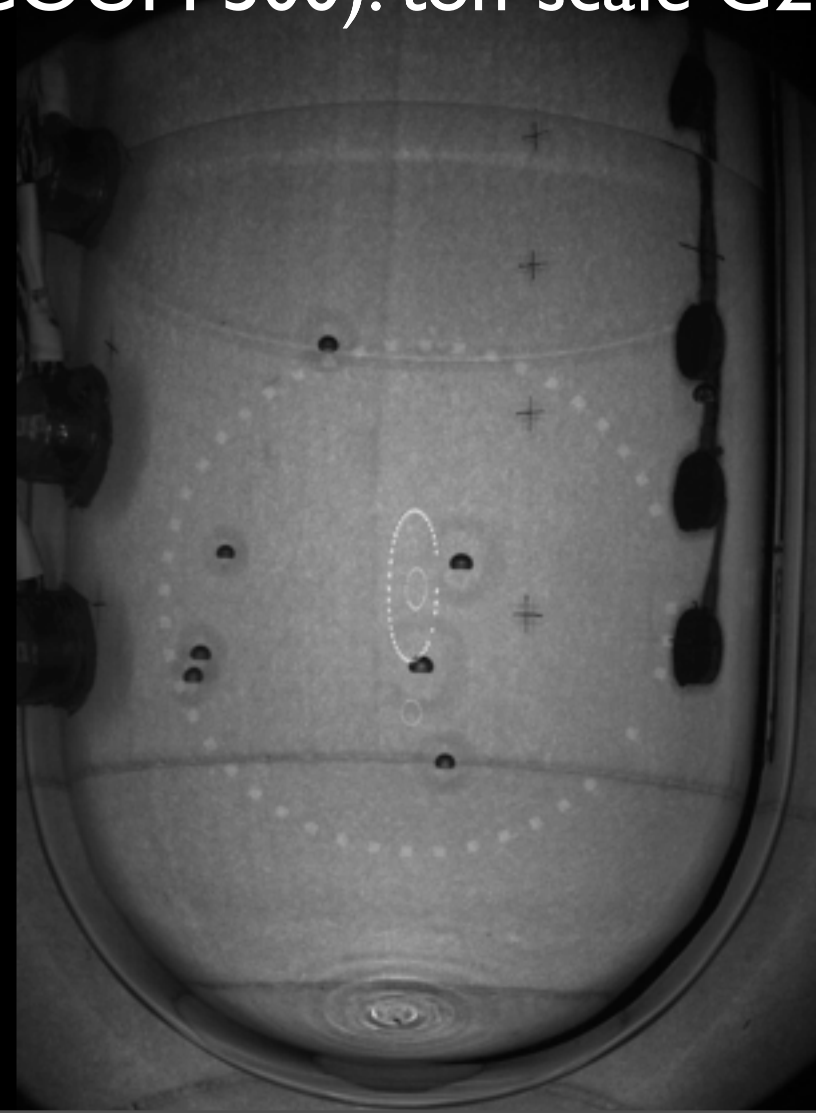
- Discovery of acoustic discrimination against alphas by PICASSO (Aubin et al, New J. Phys 10:103017, 2008)
  - Alphas deposit energy over tens of microns
  - Nuclear recoils deposit theirs in tens of nanometers
- In COUPP bubble chambers, alphas are several times louder

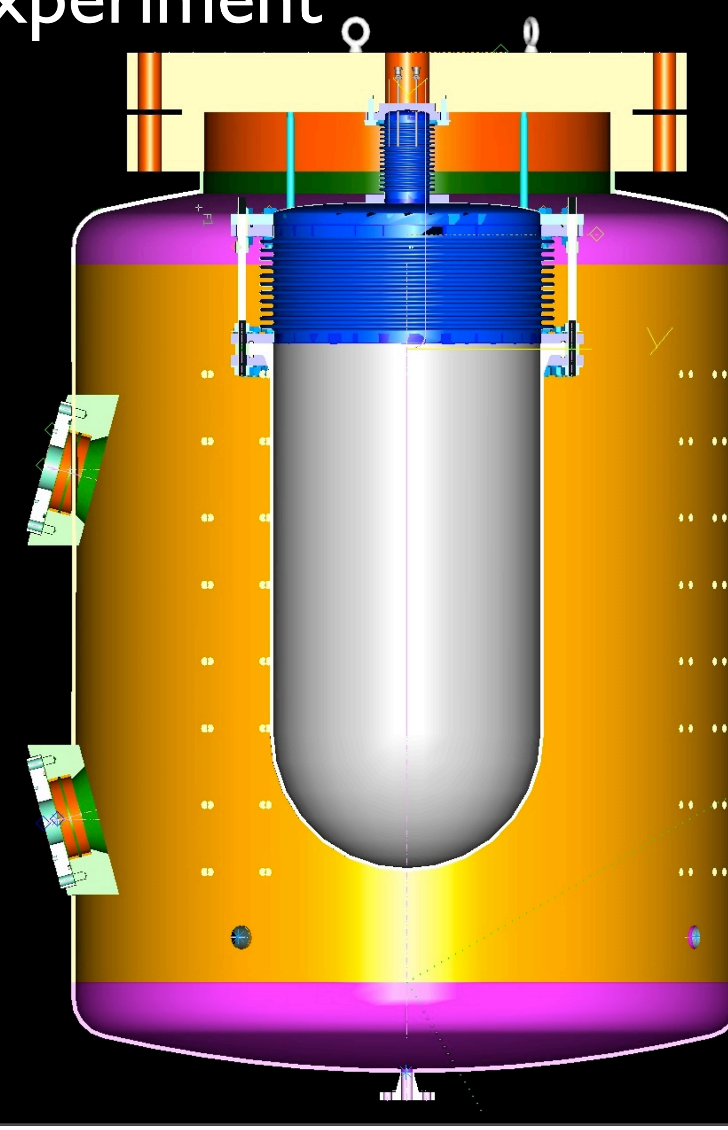


The COUPP/PICO program

- COUPP4: A 2-liter chamber run at SNOLAB in 2010-2012
  - PICO-2L: see talk from R. Neilson, Session DM 2
- COUPP60: Up to 40 liters, running at SNOLAB now
- PICO-250L (formerly COUPP500): ton-scale G2 experiment



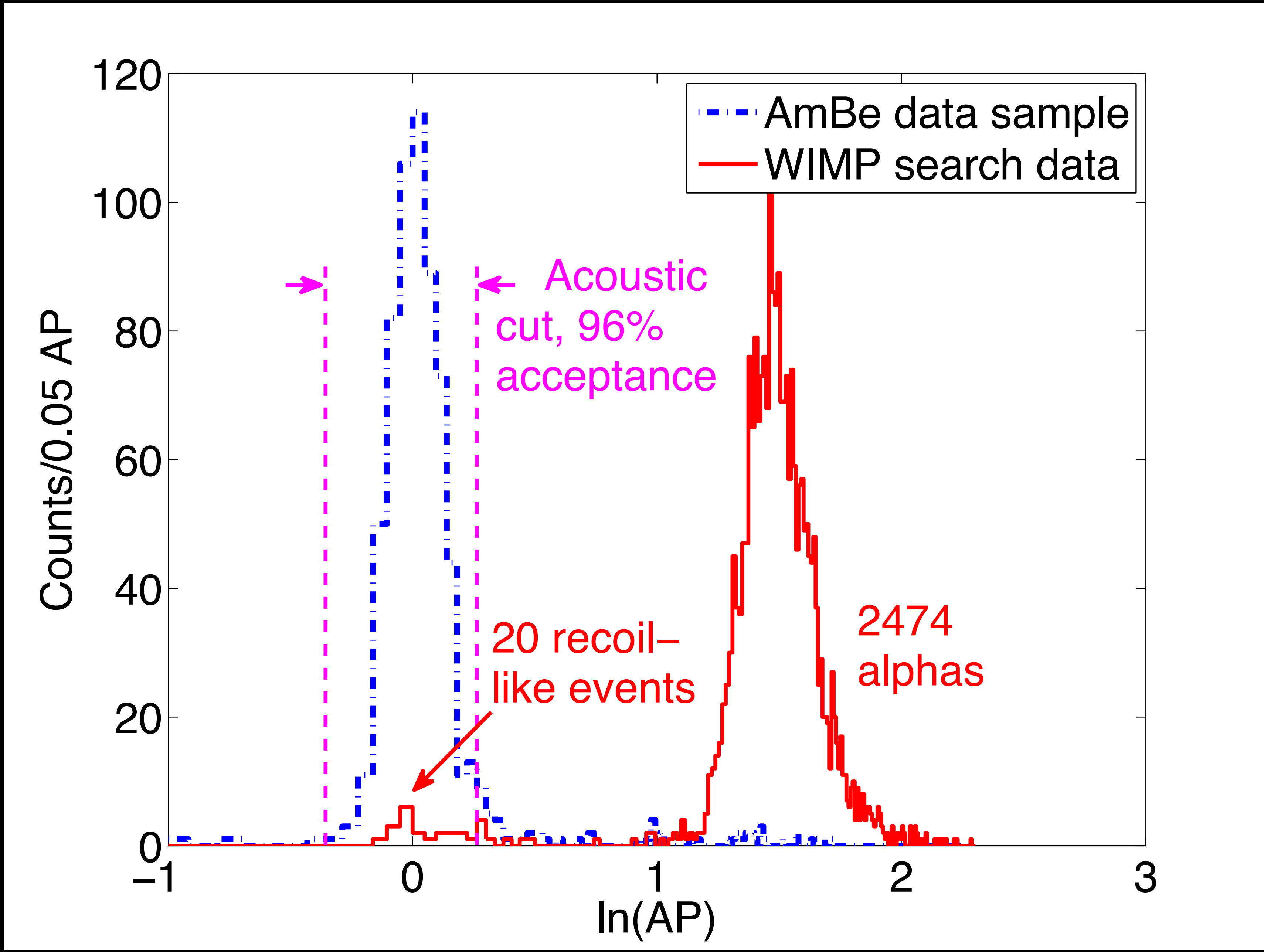




COUPP-4

COUPP4: Acoustic discrimination

- Better than 99.3% rejection against alphas at 16 keV threshold
  - Limited by statistics, and backgrounds

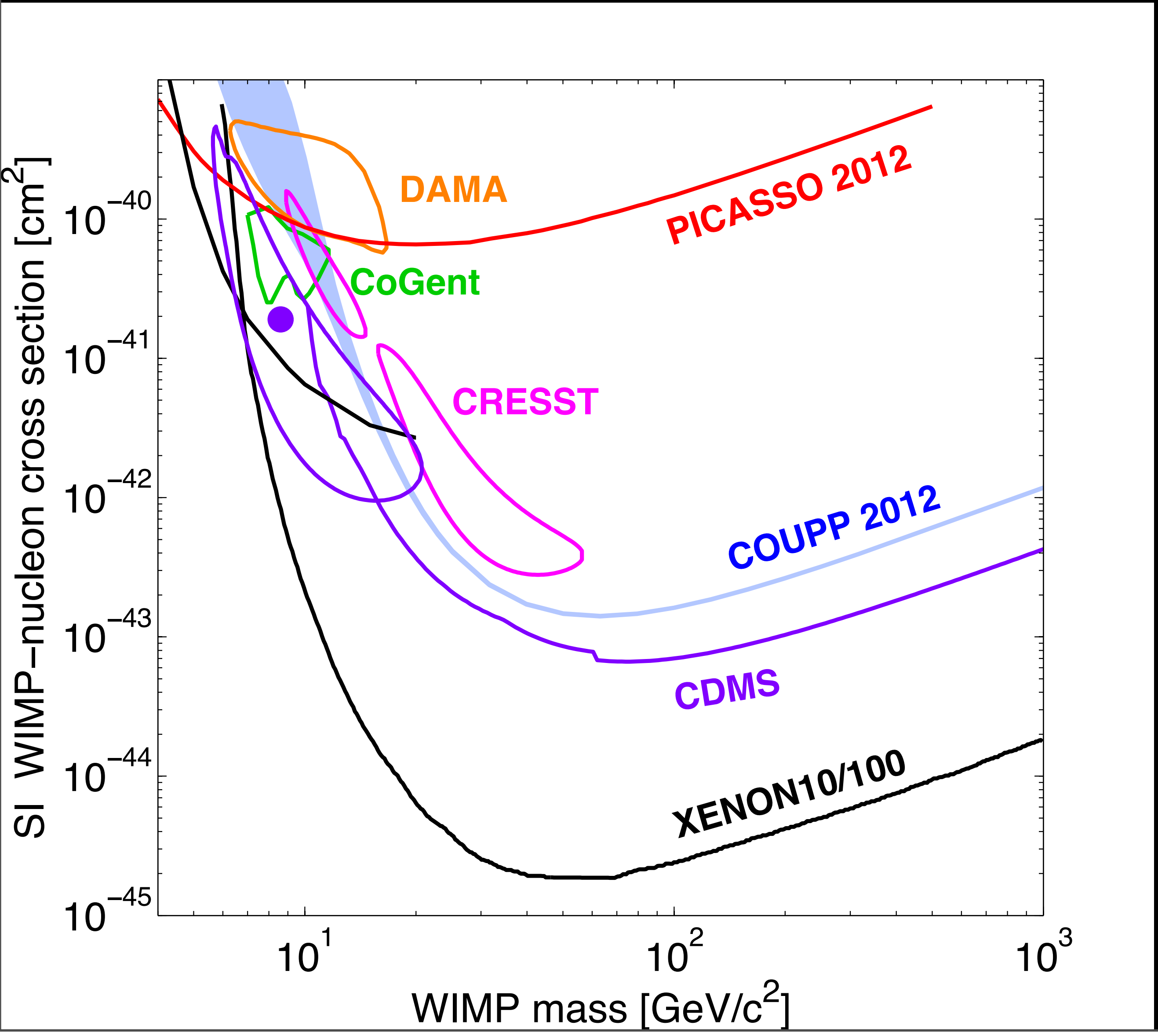


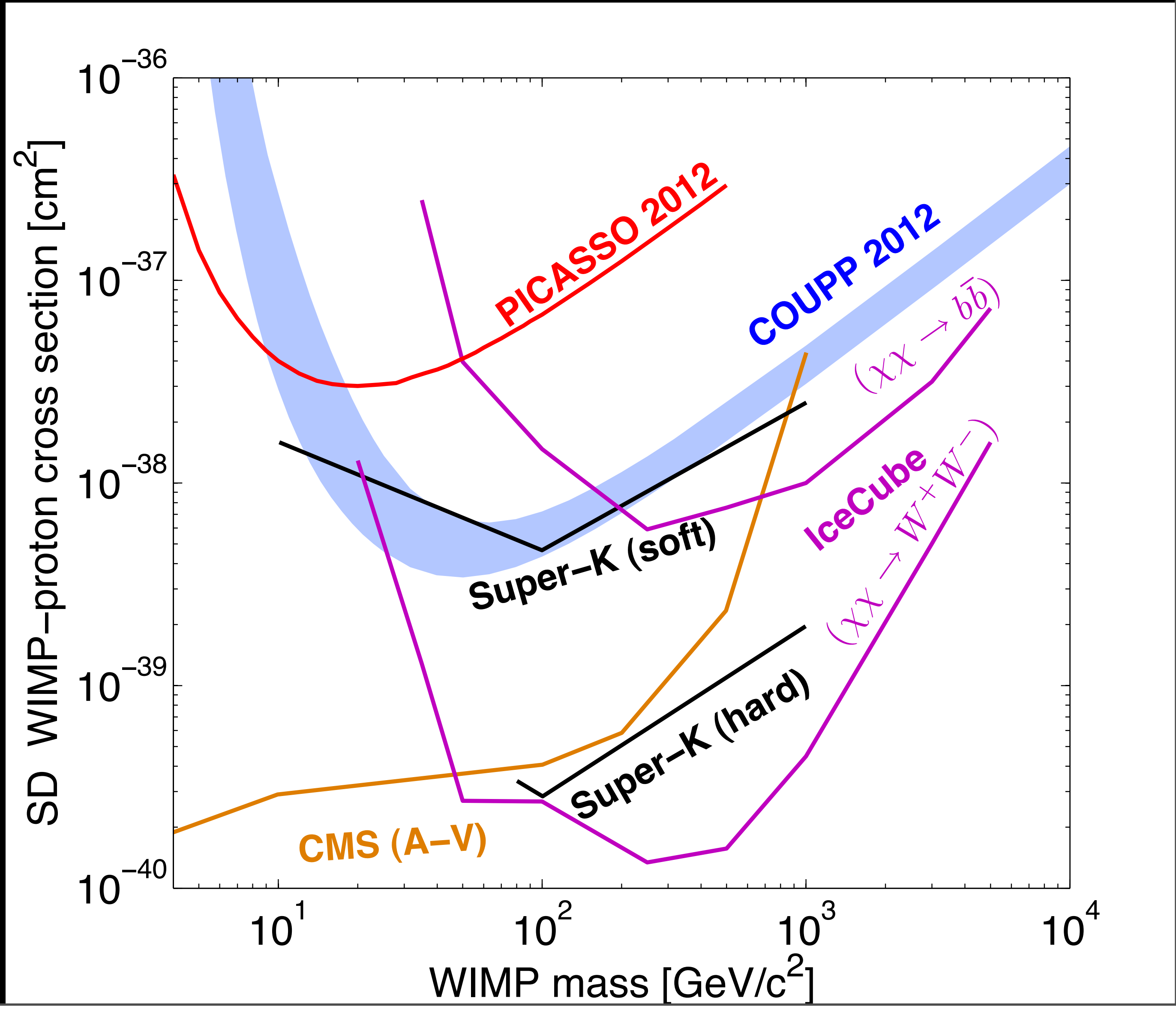
COUPP4: Results and sensitivity

- 20 WIMP candidates (6 at 8 keV, 6 at 11 keV, 8 at 16 keV)
    - 3 multiple bubble events imply some contribution from neutrons
    - U, Th in the piezo-acoustic sensors and the viewports
- Remaining excess of singles at low threshold
    - Time clustering
    - Correlated with activity at water-CF_3I interface

COUPP4: Results and sensitivity

- Results in PRD 86:052001 (2012)
- Second run in 2012 observed same phenomena (Eric Vazquez Jauregui, Moriond, 2013)



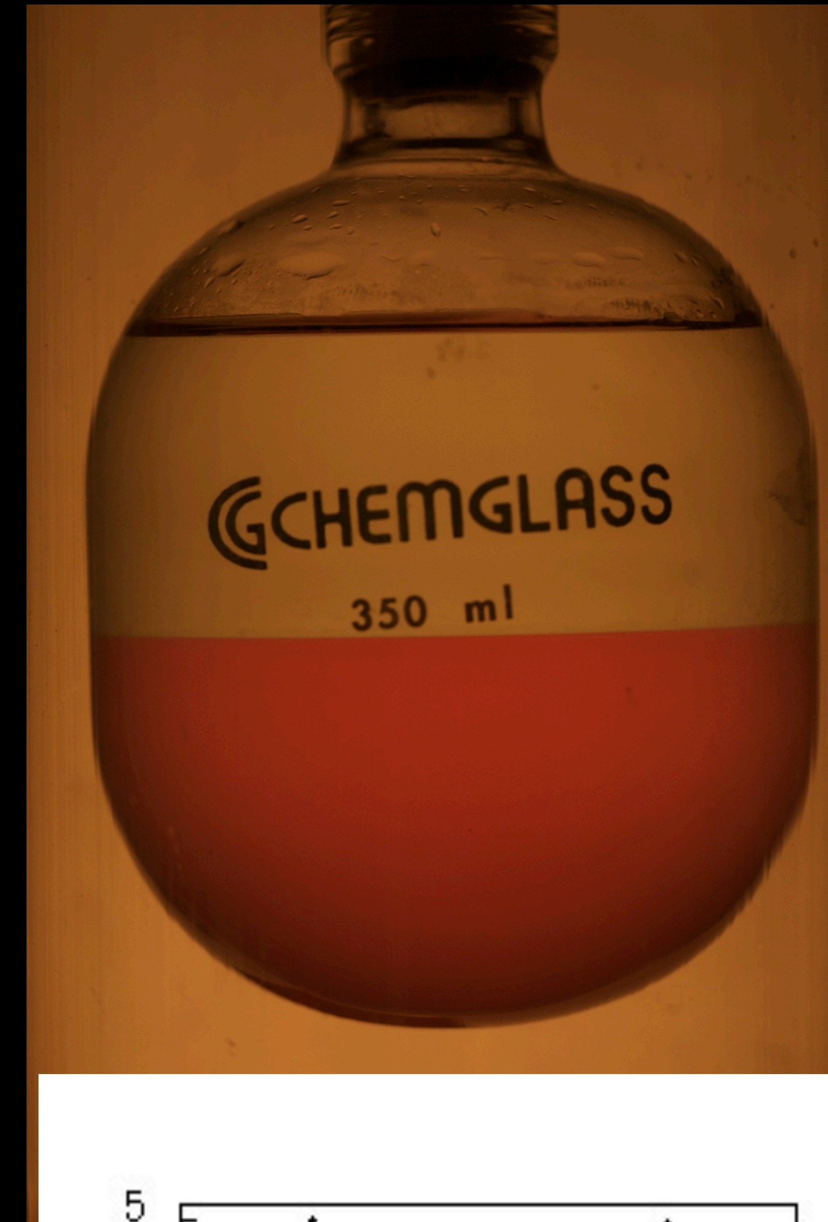


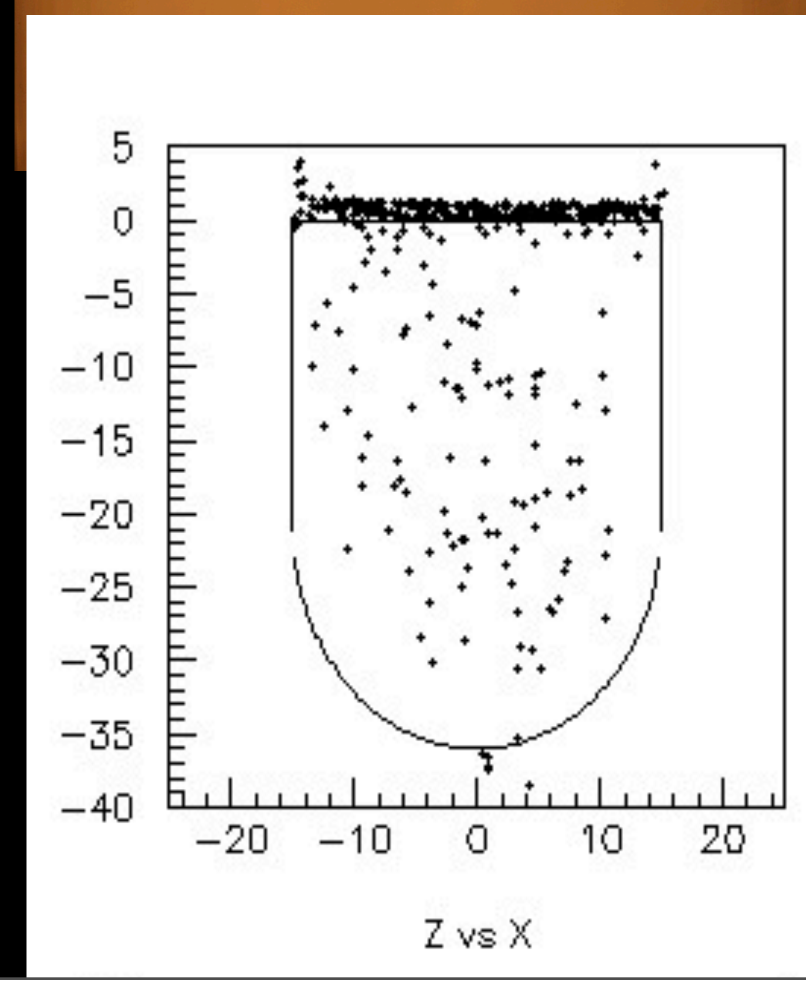
COUPP60

- Engineering run at shallow site in 2010
  - Low backgrounds and acoustic discrimination

COUPP60

- Engineering run at shallow site in 2010
  - Low backgrounds and acoustic discrimination
  - Fluid darkening due to photodissociation of iodine
  - Excessive surface rate

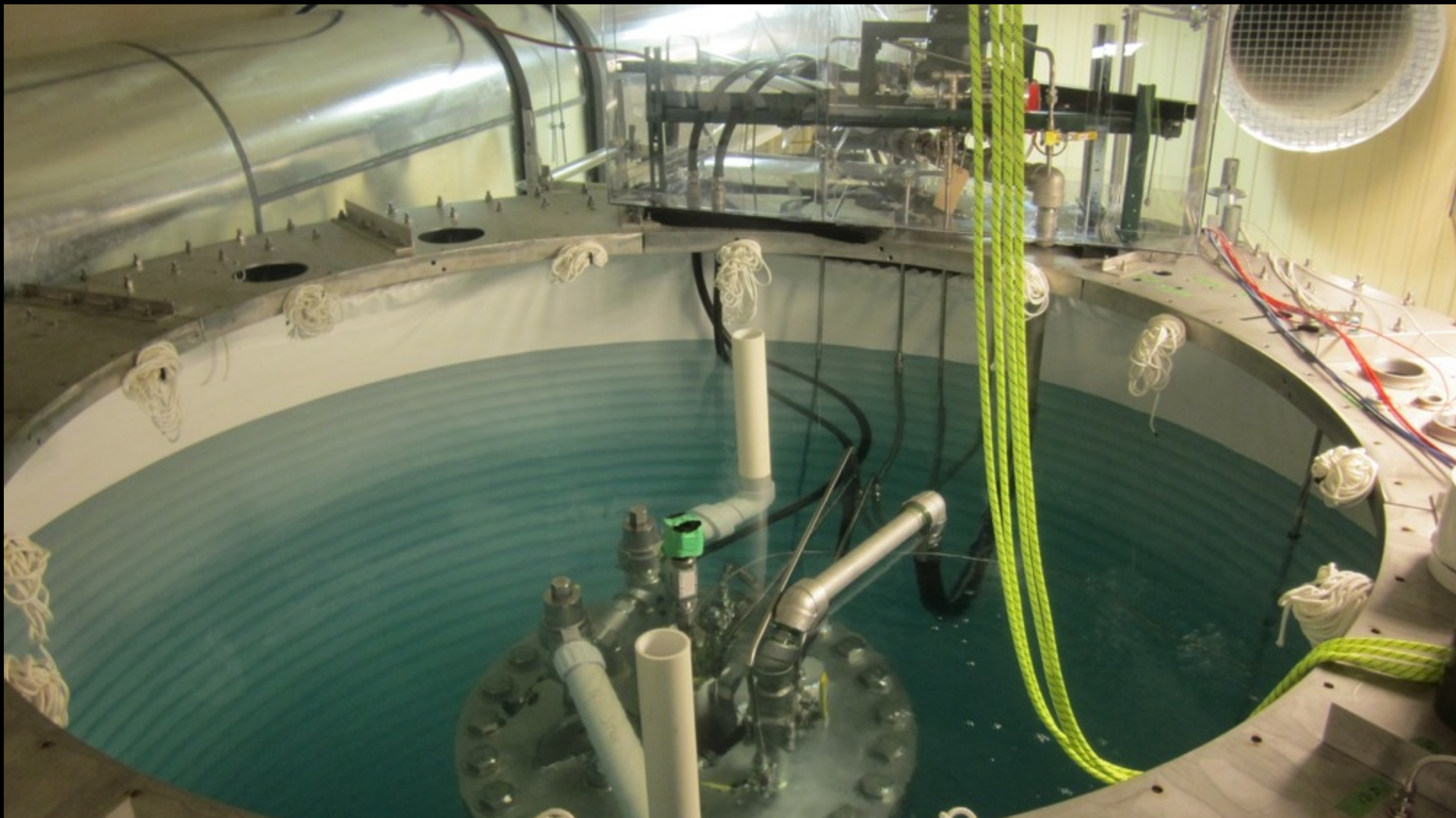




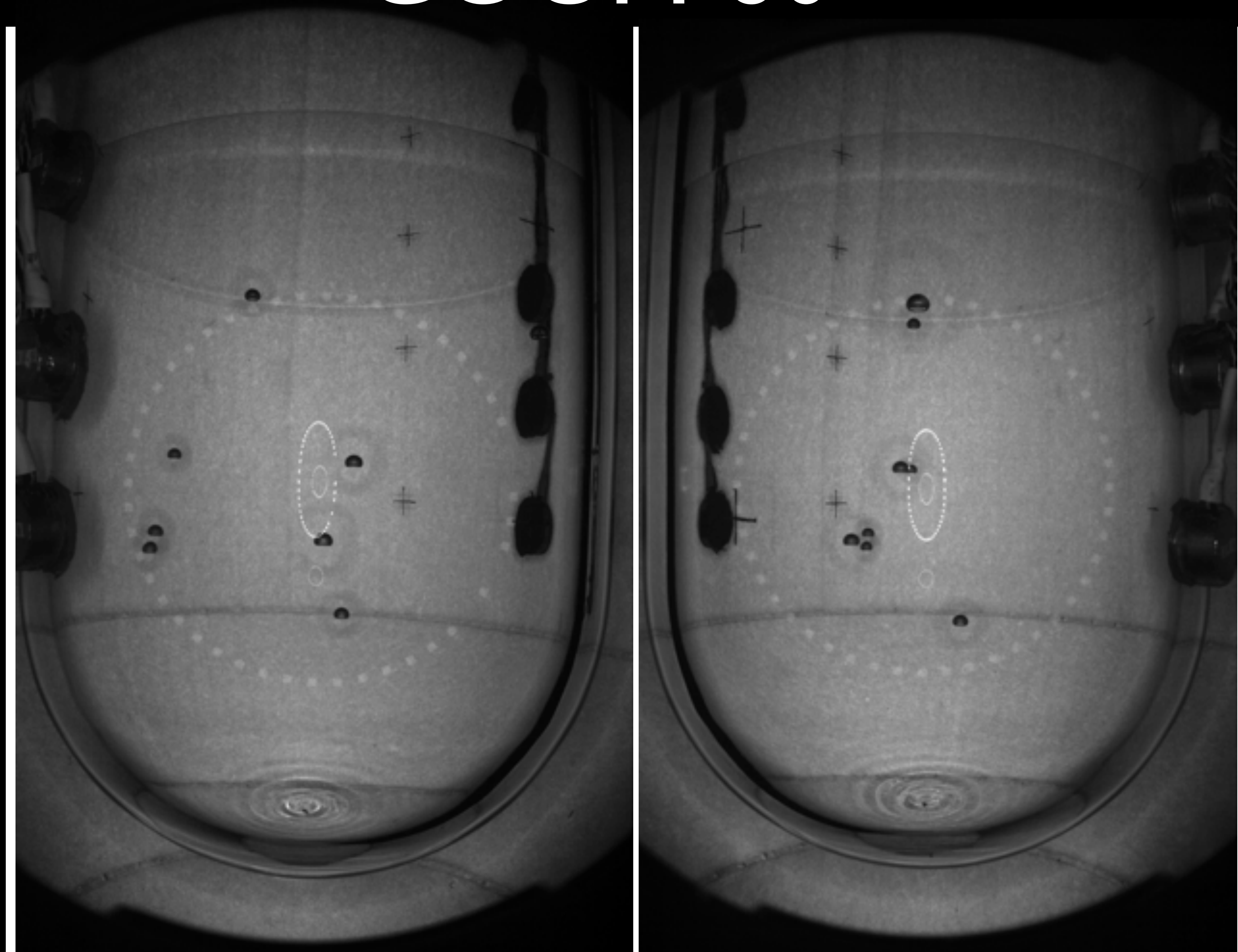
COUPP60

- Engineering run at shallow site in 2010
  - Low backgrounds and acoustic discrimination
  - Fluid darkening due to photodissociation of iodine
  - Excessive surface rate
- Solutions tested in second run November, 2011
- Started moving to SNOLAB last summer


CYLINDER
EMPTY
IN USE

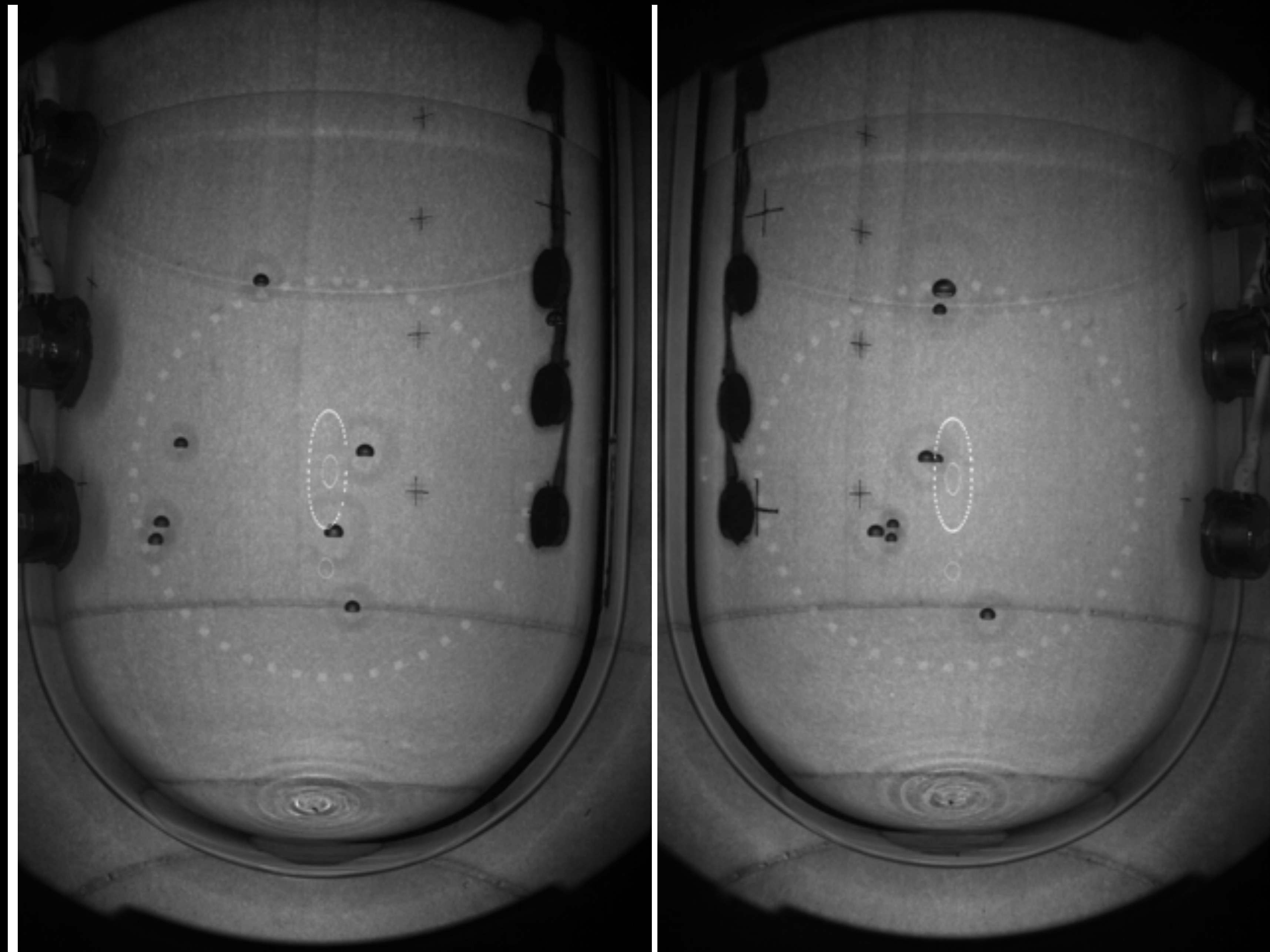


COUPP60



- Filled with 36.8 kg of CF_3I at end of April
- First bubble observed on May 1(radon decay)
- Physics data started June 13

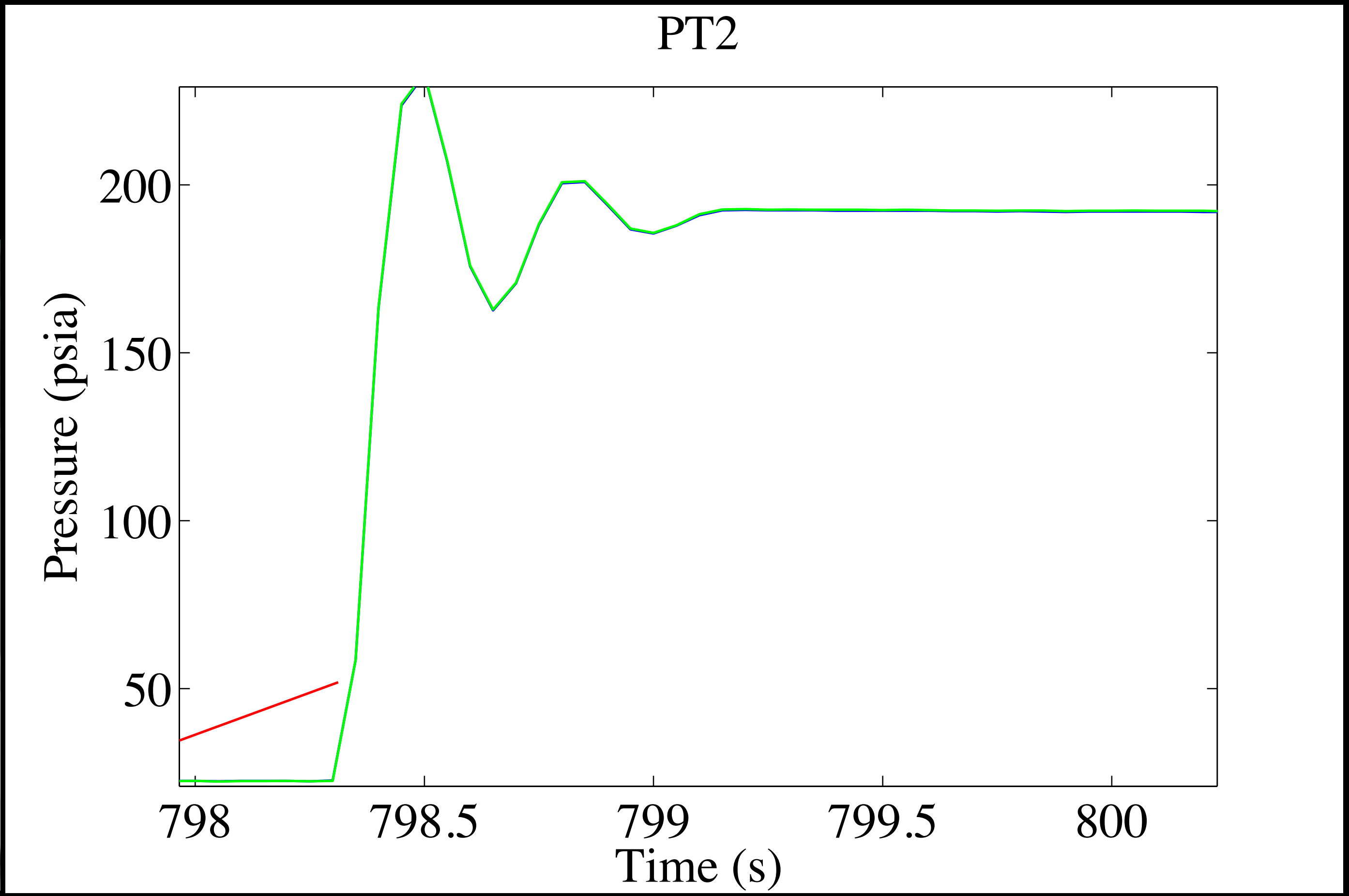
COUPP60



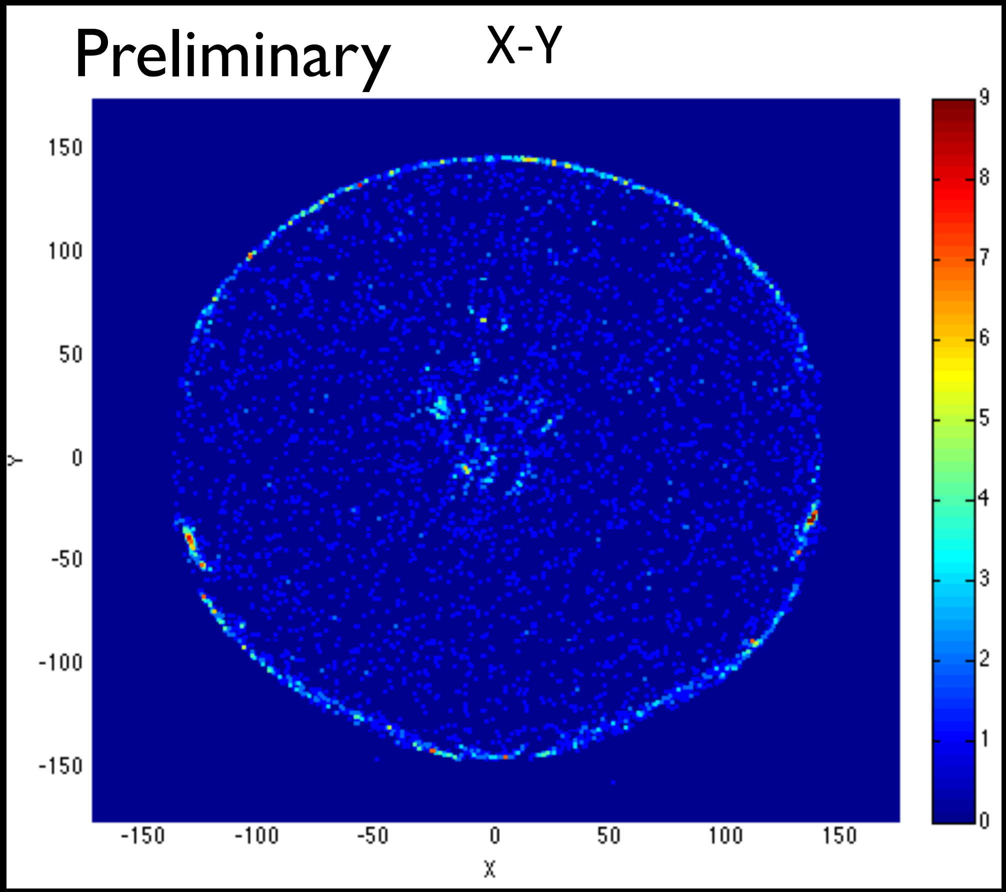
- Collected 1378 kg-days of dark matter search data between 10 and 20 keV threshold
  - Good live fraction > 80%, no darkening
- >1500 neutron source events from calibration runs

COUPP60

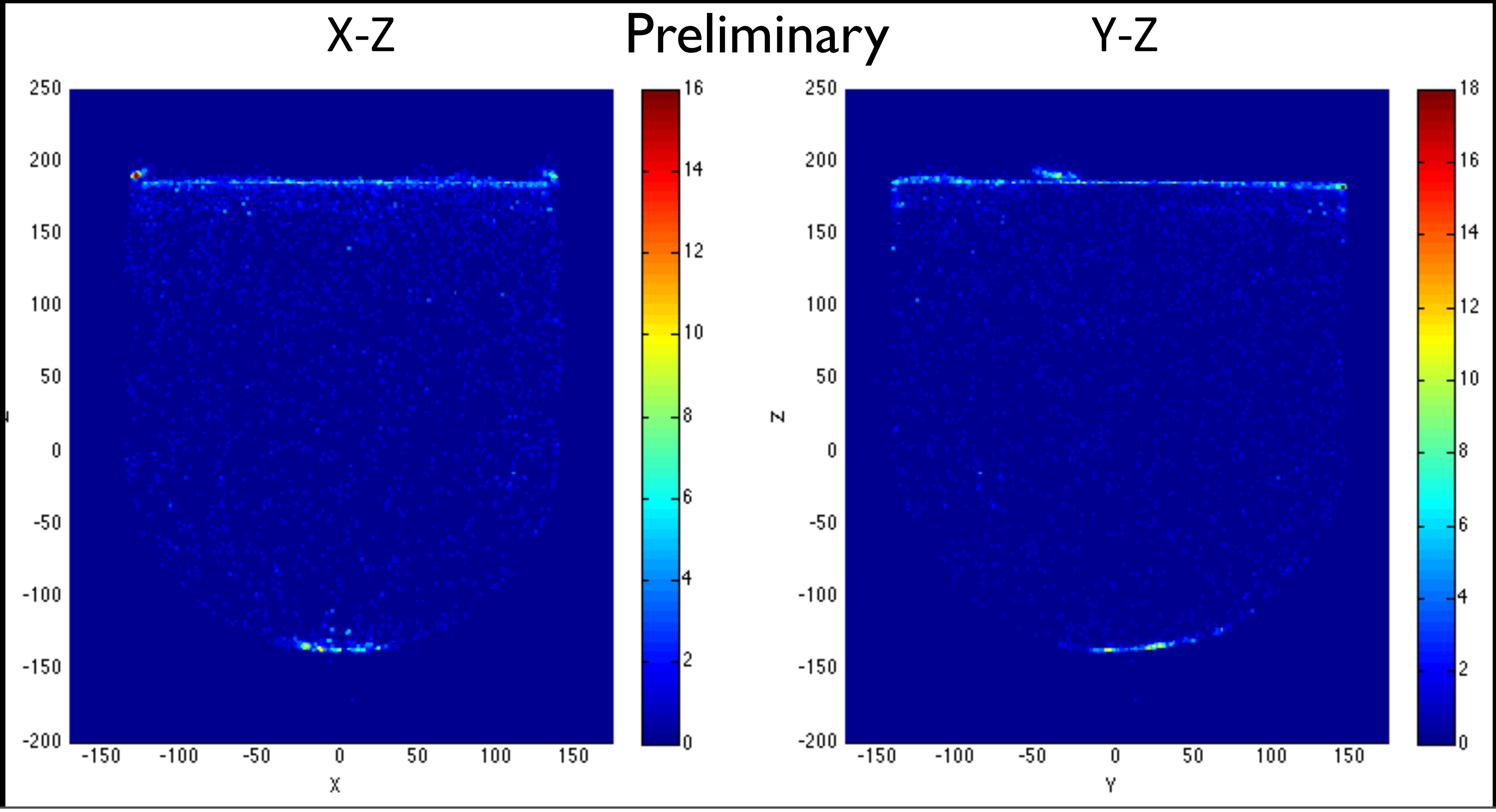
- August 9, we discovered a small hydraulic leak
- We stopped cycling the chamber, leak closed up
  - Most likely scenario is pressure relief opening on compression
- Operations on hold until we can get into the water tank and fix the problem
- Will be running again in a couple of weeks



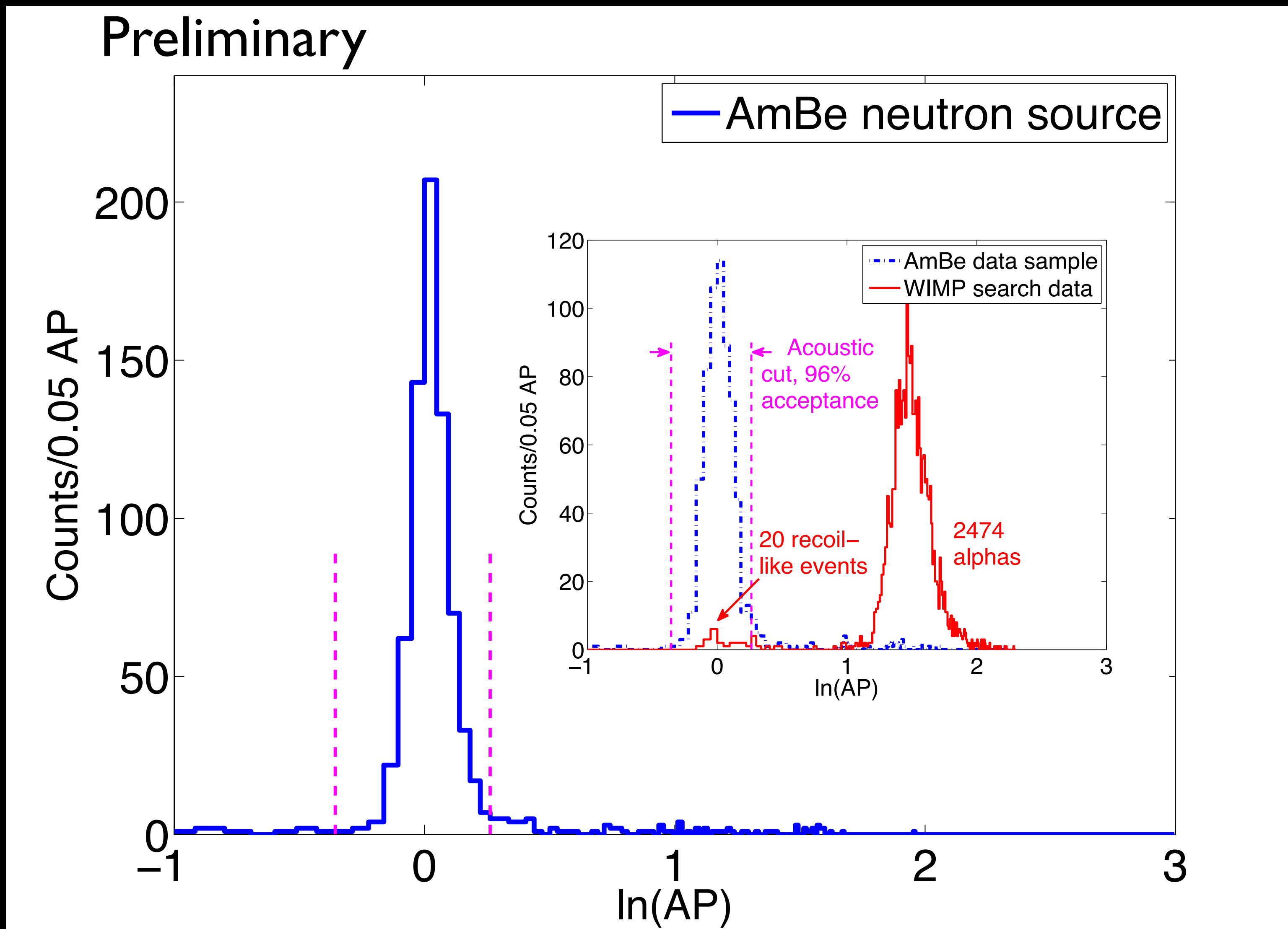
COUPP60 - the data



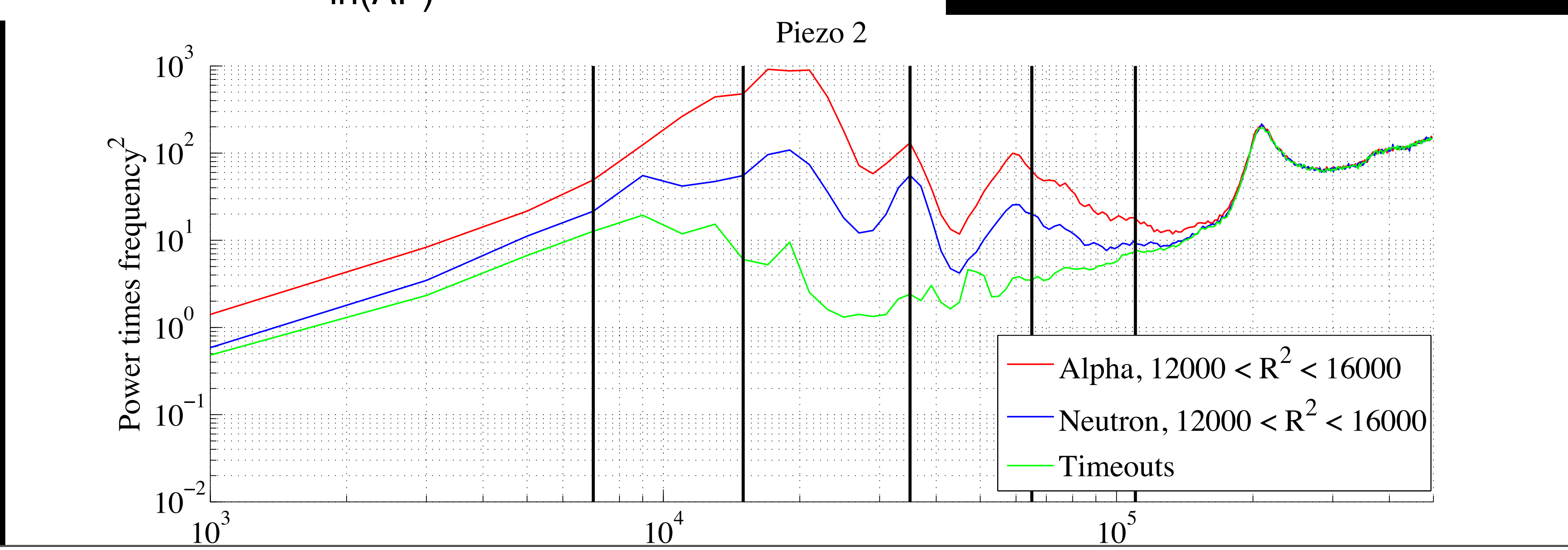
- Position reconstruction working well
- Clear set of events on surface and hemisphere
  - Not a background, and rate is under control



COUPP60 - the data

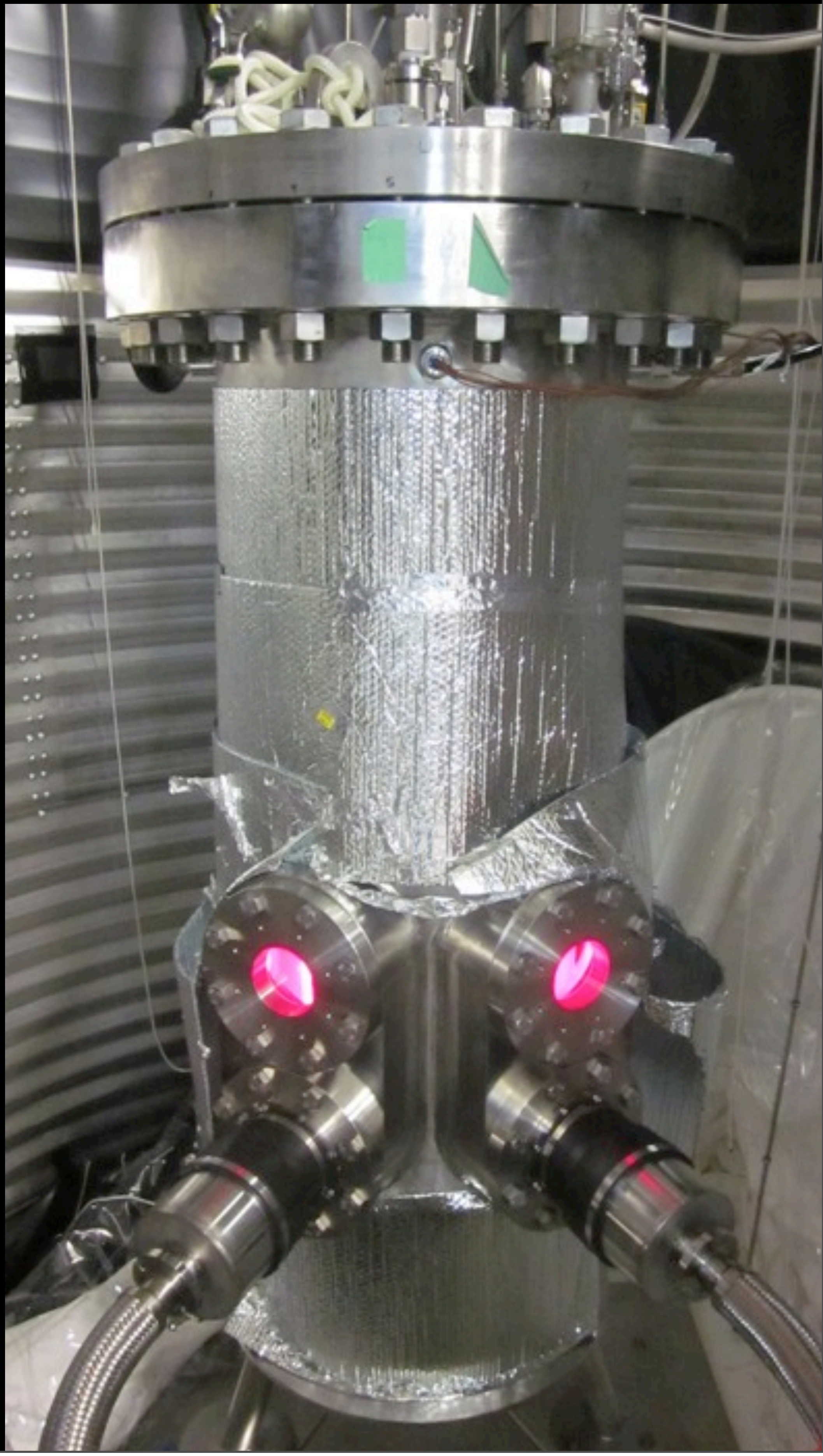


- Acoustics are working well
  - Calibration data show a narrower distribution than COUPP4
- Alpha discrimination still very strong



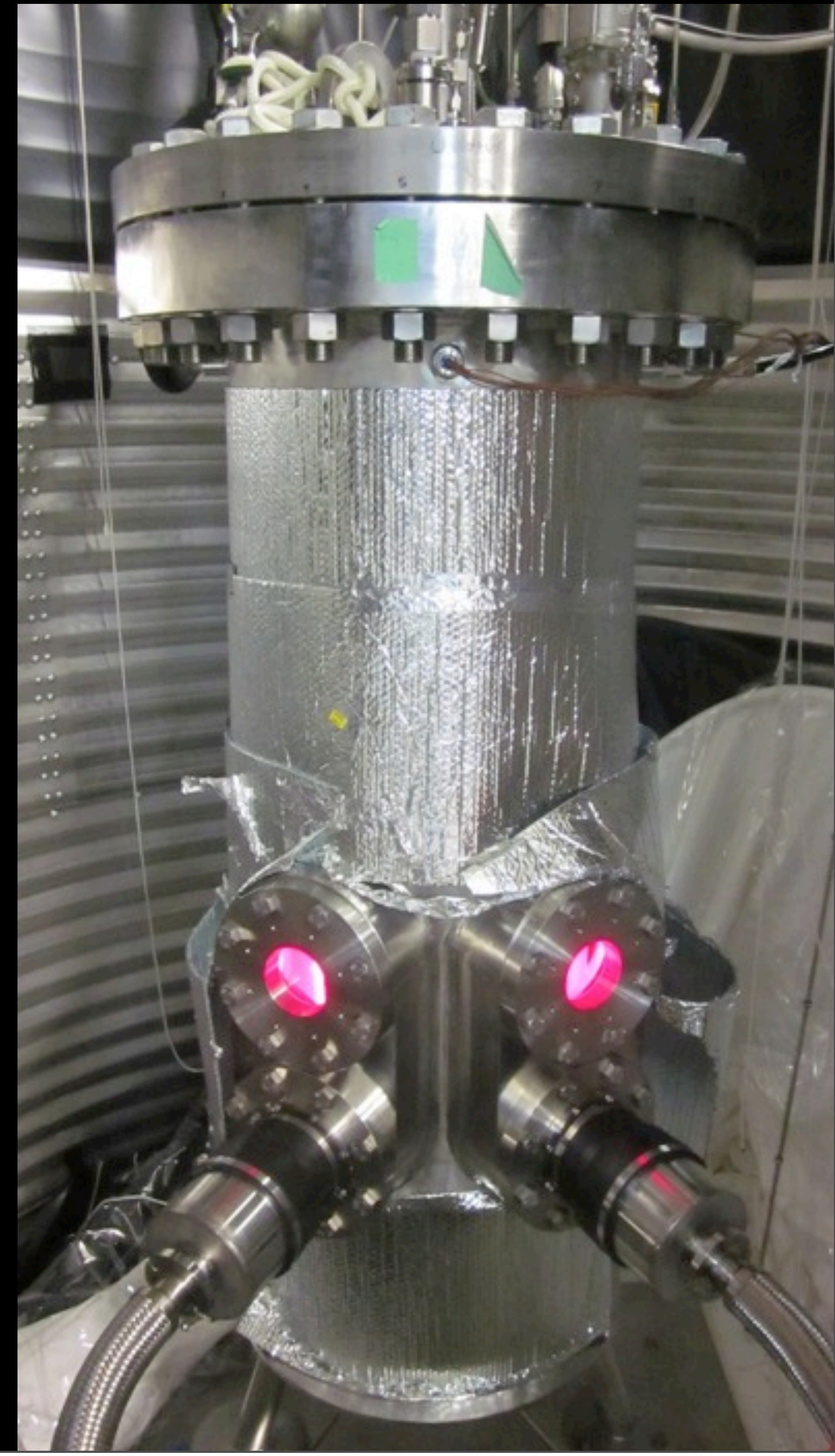
COUPP60 - the data

- Analysis still under development
- Good news:
- Bad news:



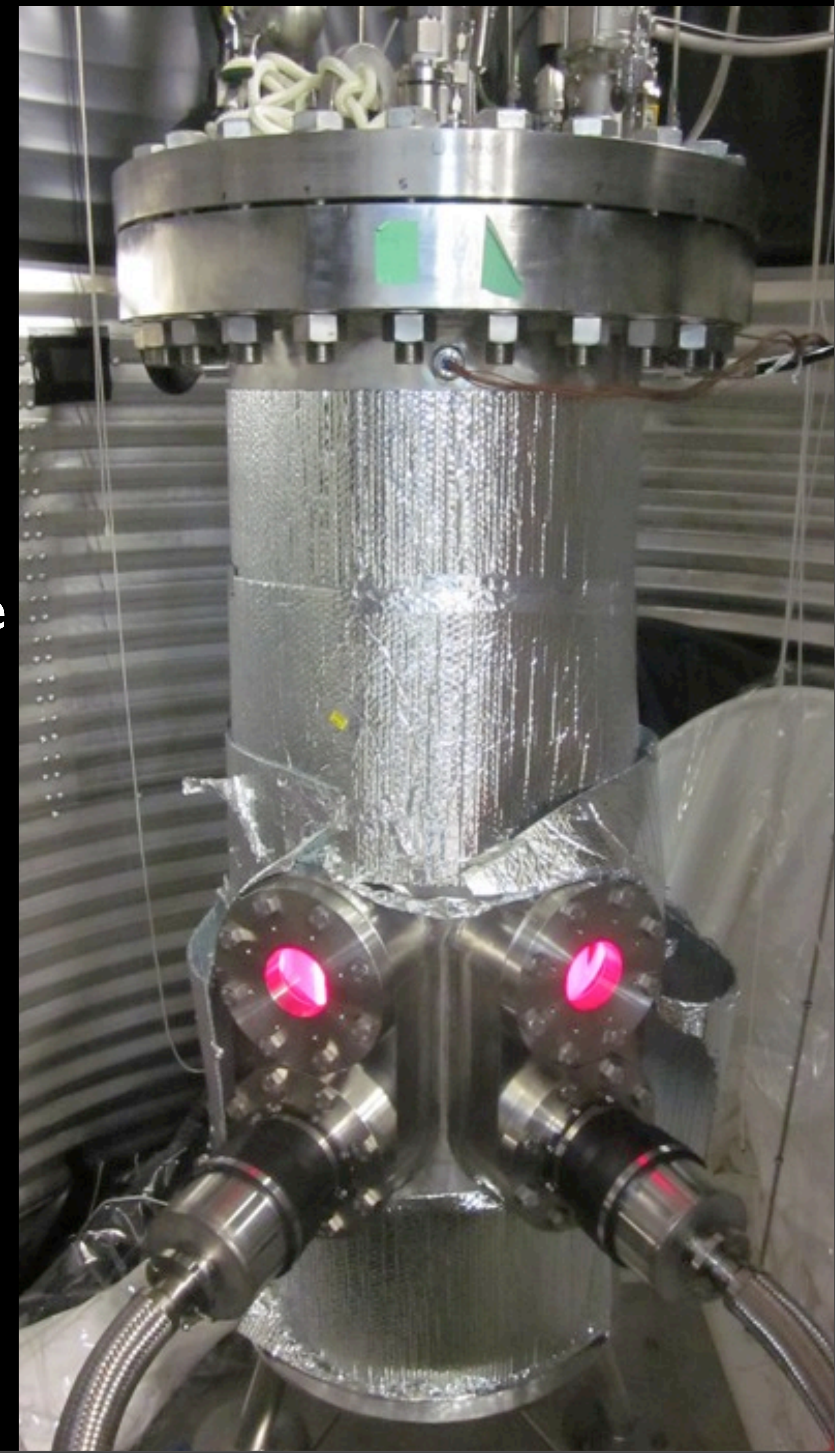
COUPP60 - the data

- Analysis still under development
- Good news: Zero multiple bubbles, no neutrons. Limit on neutron rate is factor 3 below observed rate in COUPP4
- Bad news:



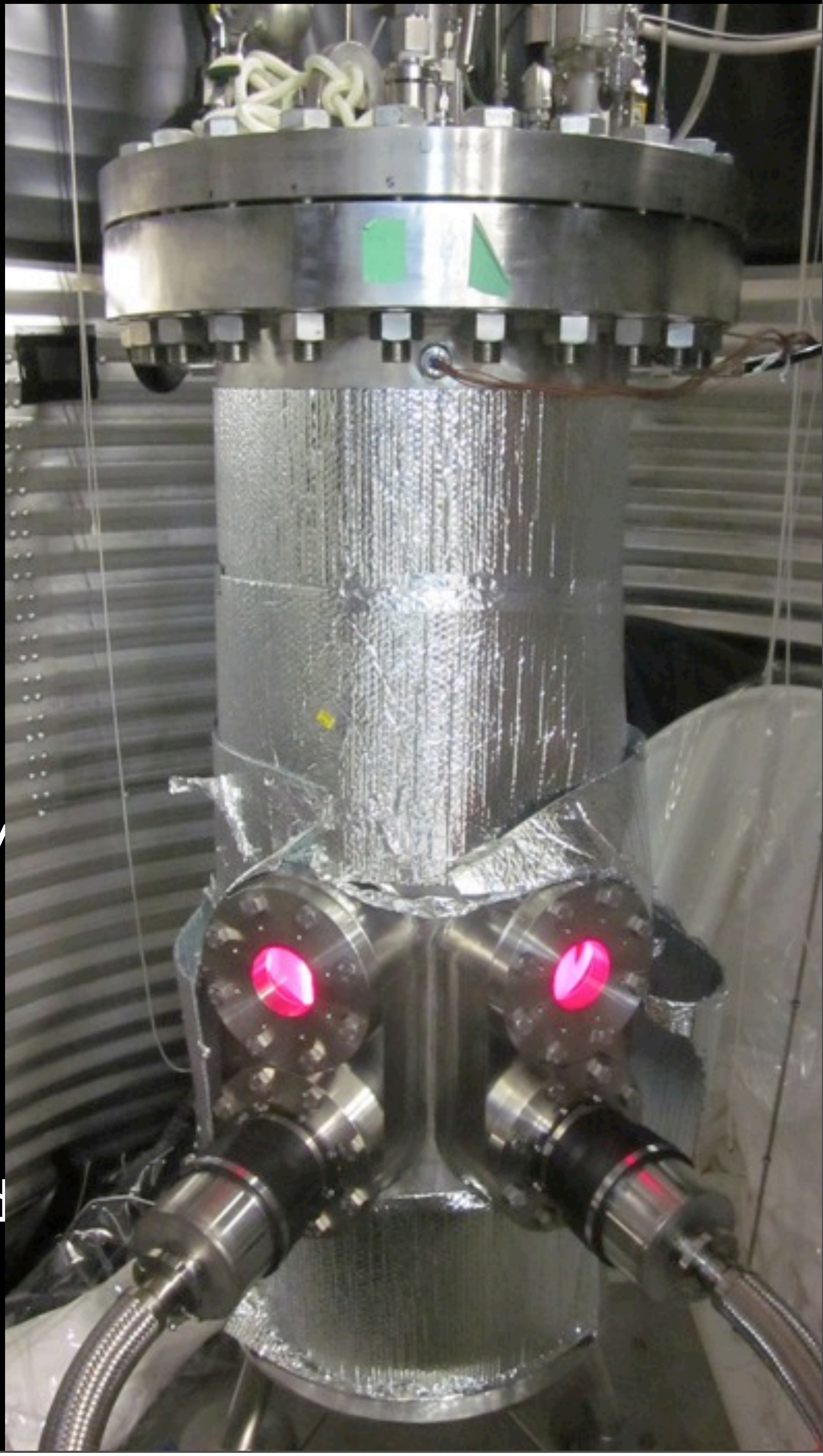
COUPP60 - the data

- Analysis still under development
- Good news: Zero multiple bubbles, no neutrons. Limit on neutron rate is factor 3 below observed rate in COUPP4
- Bad news: Population of events that sound like nuclear recoils but are clearly not WIMPs
  - Silver lining:



COUPP60 - the data

- Analysis still under development
- Good news: Zero multiple bubbles, no neutrons. Limit on neutron rate is factor 3 below observed rate in COUPP4
- Bad news: Population of events that sound like nuclear recoils but are clearly not WIMPs
  - Silver lining: statistics - we can actually study them in detail
  - Early indications confirm a slightly different acoustic distribution and similar timing and spatial correlations to COUPP4 background for at least some fraction of events

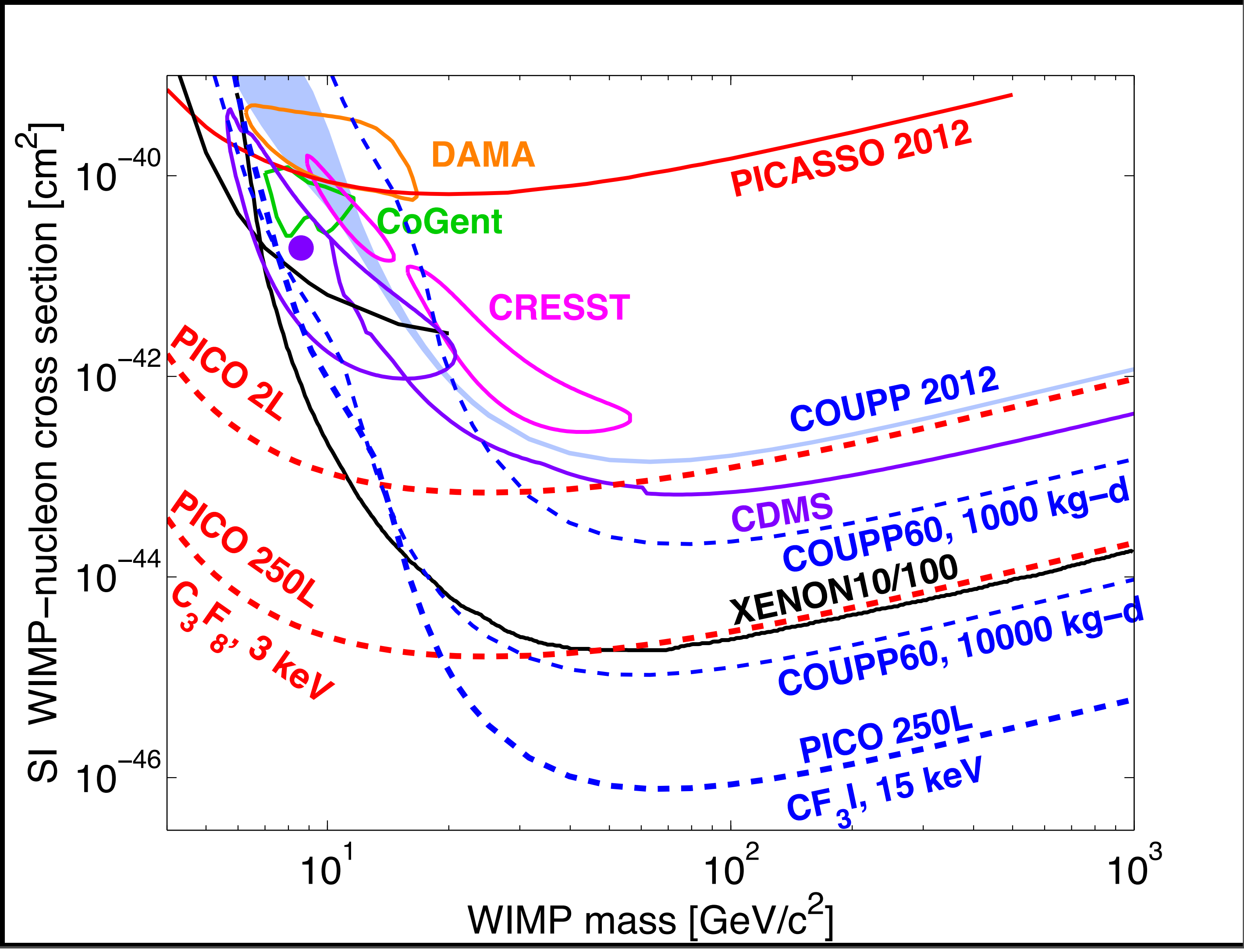


COUPP60 - future plans

- Now in Phase I: Continue running until end of year at different thresholds, fully characterize the detector, first physics result

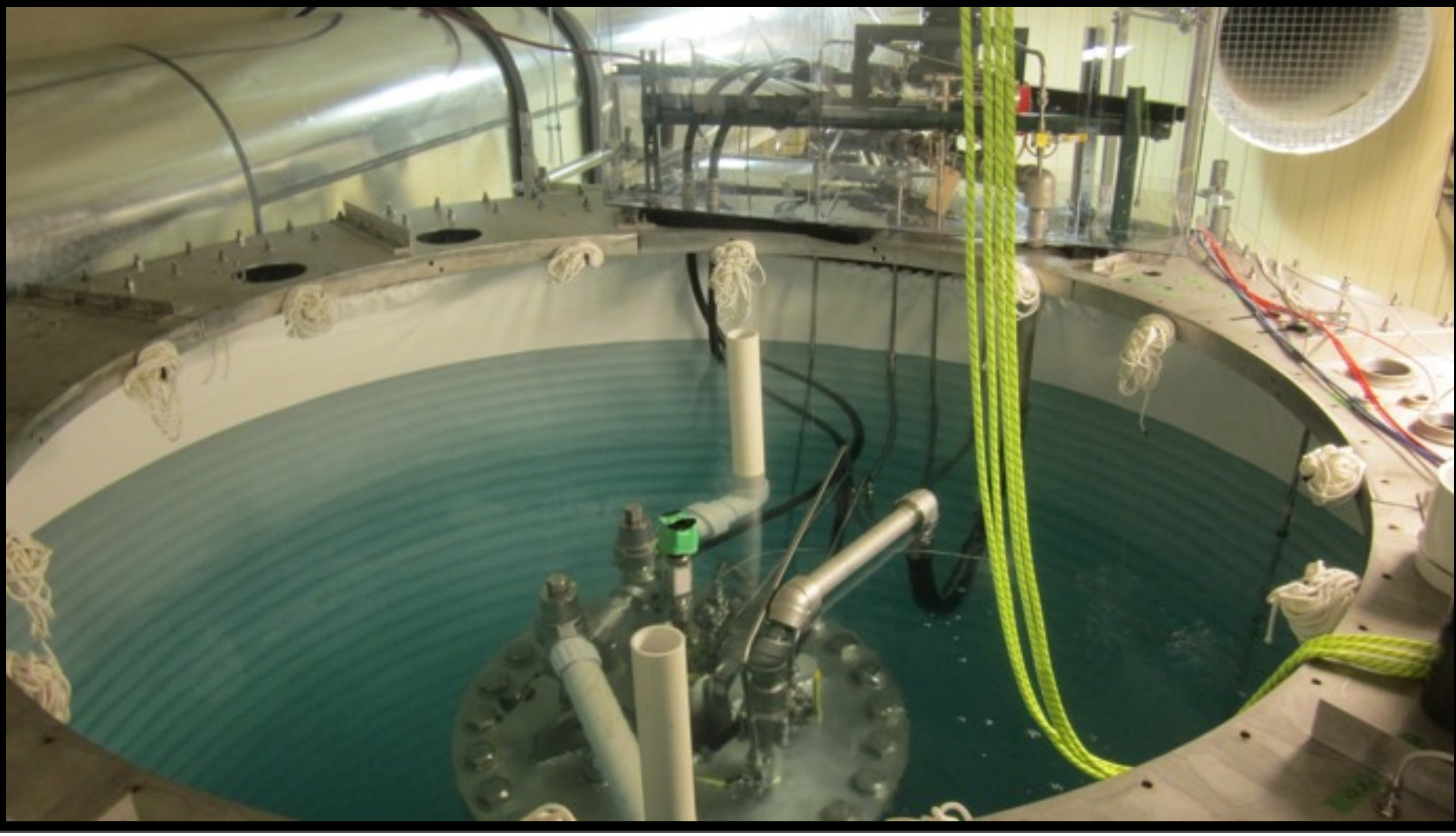
- Phase II: Upgrade to full 75 kg target with second set of cameras, collect 10000 kg-days of data

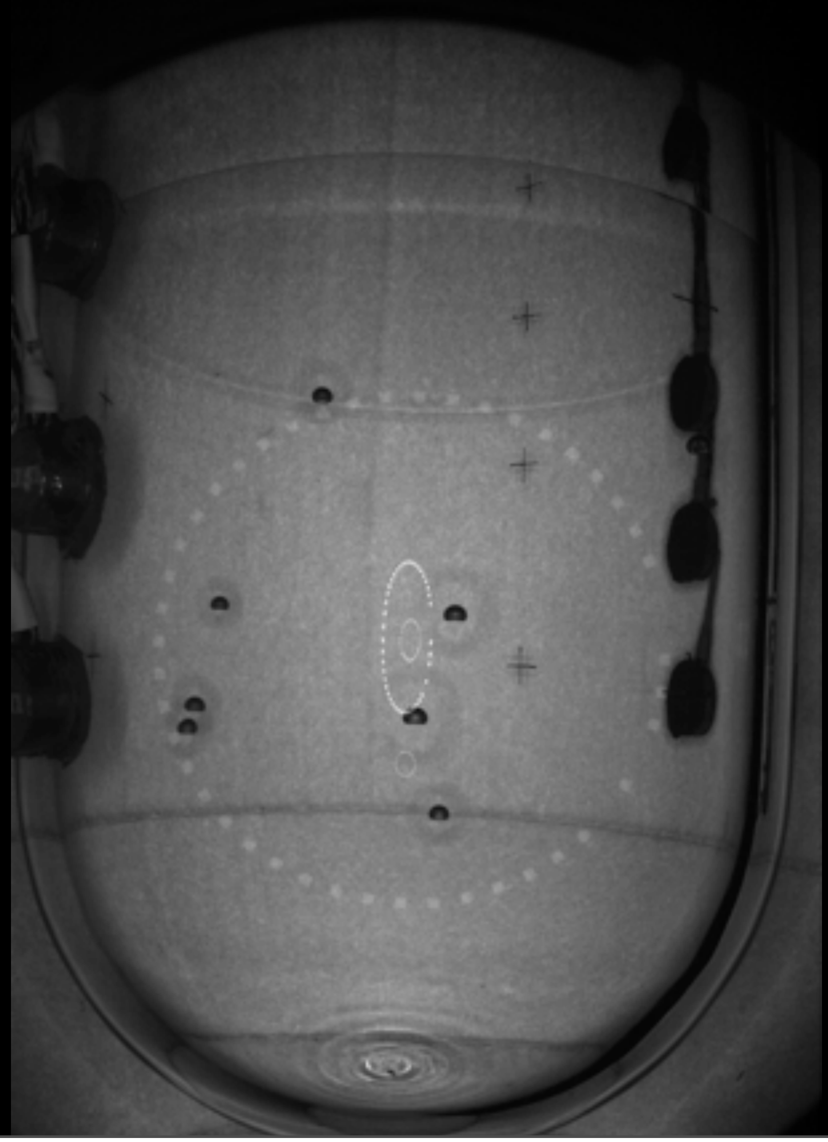
- Planned three year run with potential target swap as new information comes in



Conclusion

- COUPP60 operating well with a good live fraction (at least until the leak)
- Acoustics continue to provide good discrimination power in the larger chamber
- Still some work to do to understand the detector and extract physics - but it's early yet and who wanted it to be easy?





Extra

Detour: Threshold and efficiency

- Threshold determined from Seitz, Phys. of Fluids 1, 2 (1958)

$$p_v - p_l = \frac{2\sigma}{r_c}$$

$$E_{th} = \boxed{4\pi r_c^2 \left(\sigma - T\frac{\partial \sigma}{\partial T}\right)} + \frac{4}{3}\pi r_c^3 \rho_v h$$

Surface energy

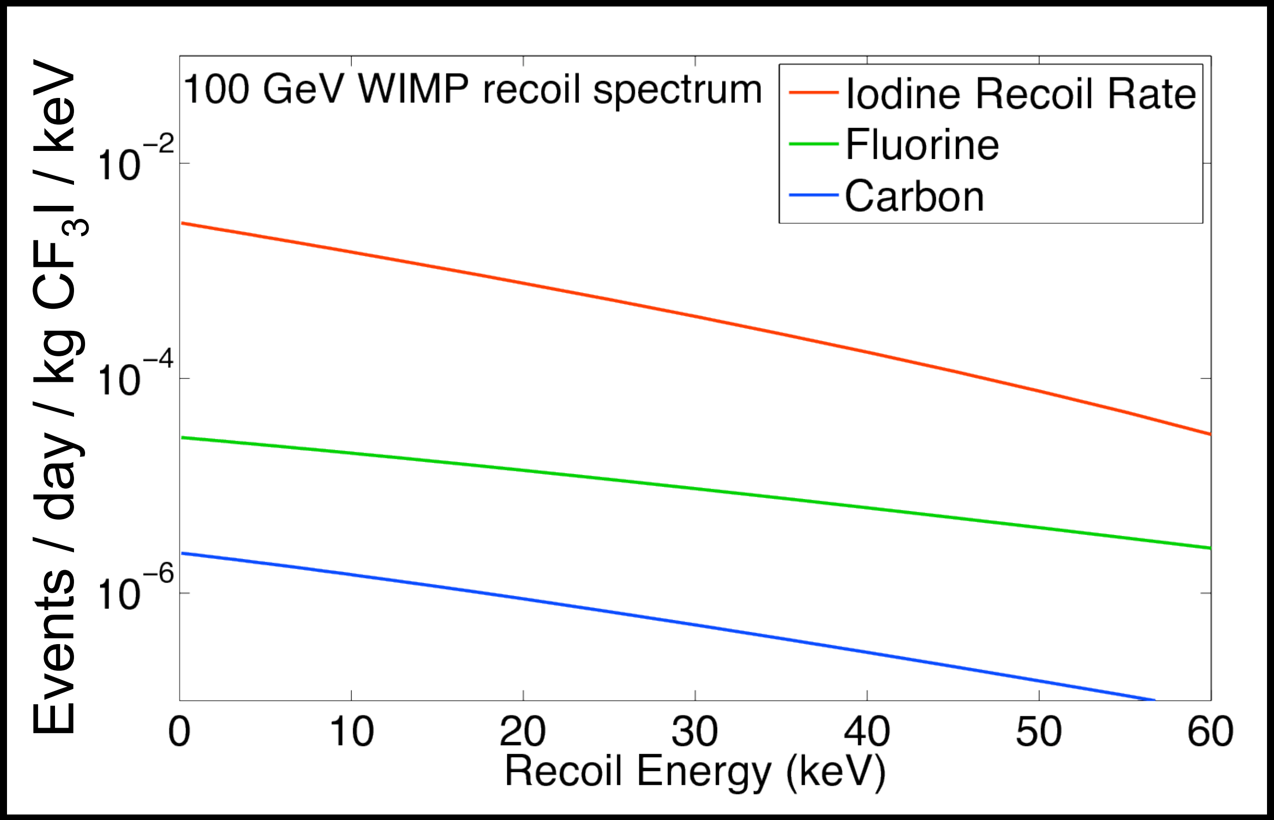
Latent heat

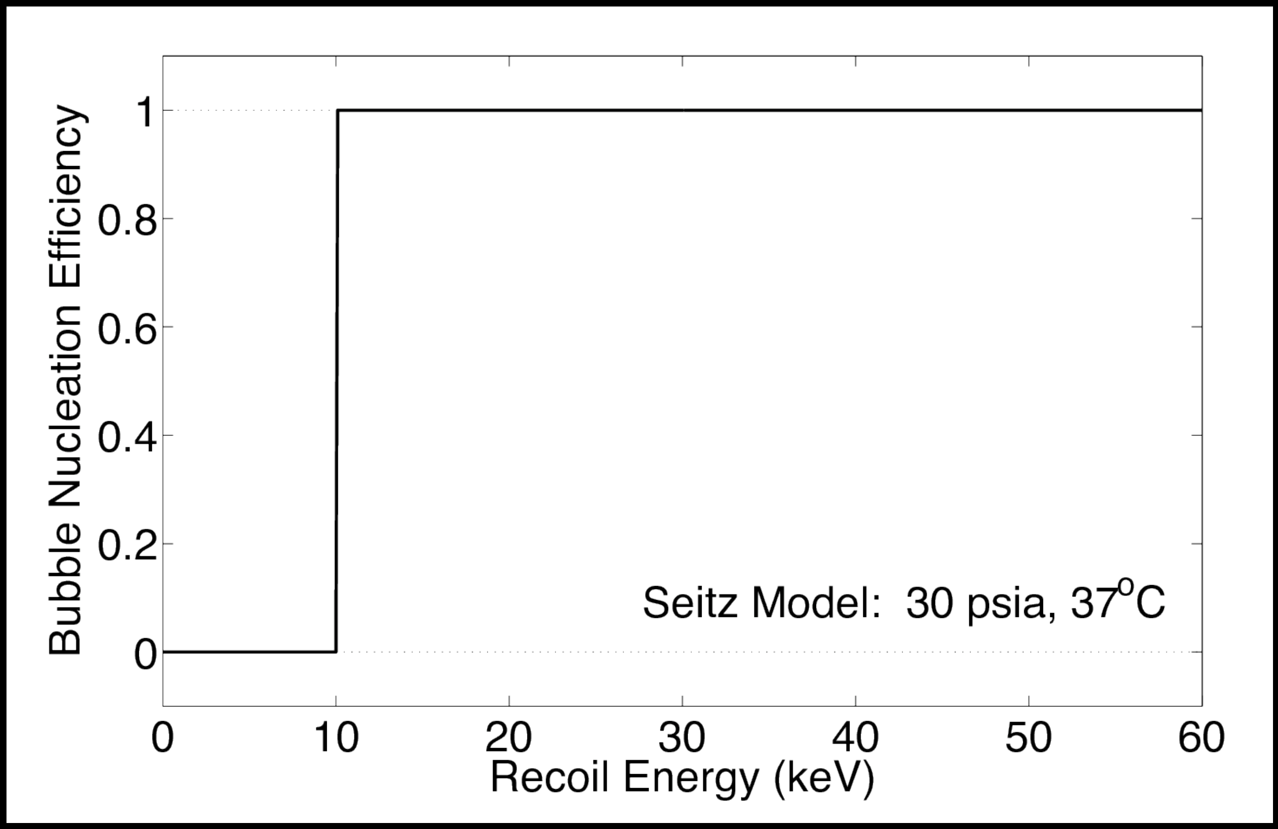
- Energy deposition E_{th} within length R_c will nucleate a bubble (Hot Spike model)

- Theory assumes a step function above threshold

Detour: Threshold and efficiency

$$\text{Rate} = \int \text{WIMP recoil spectrum} \times \text{Bubble nucleation efficiency}$$





- Effect of threshold shape depends on target, WIMP mass

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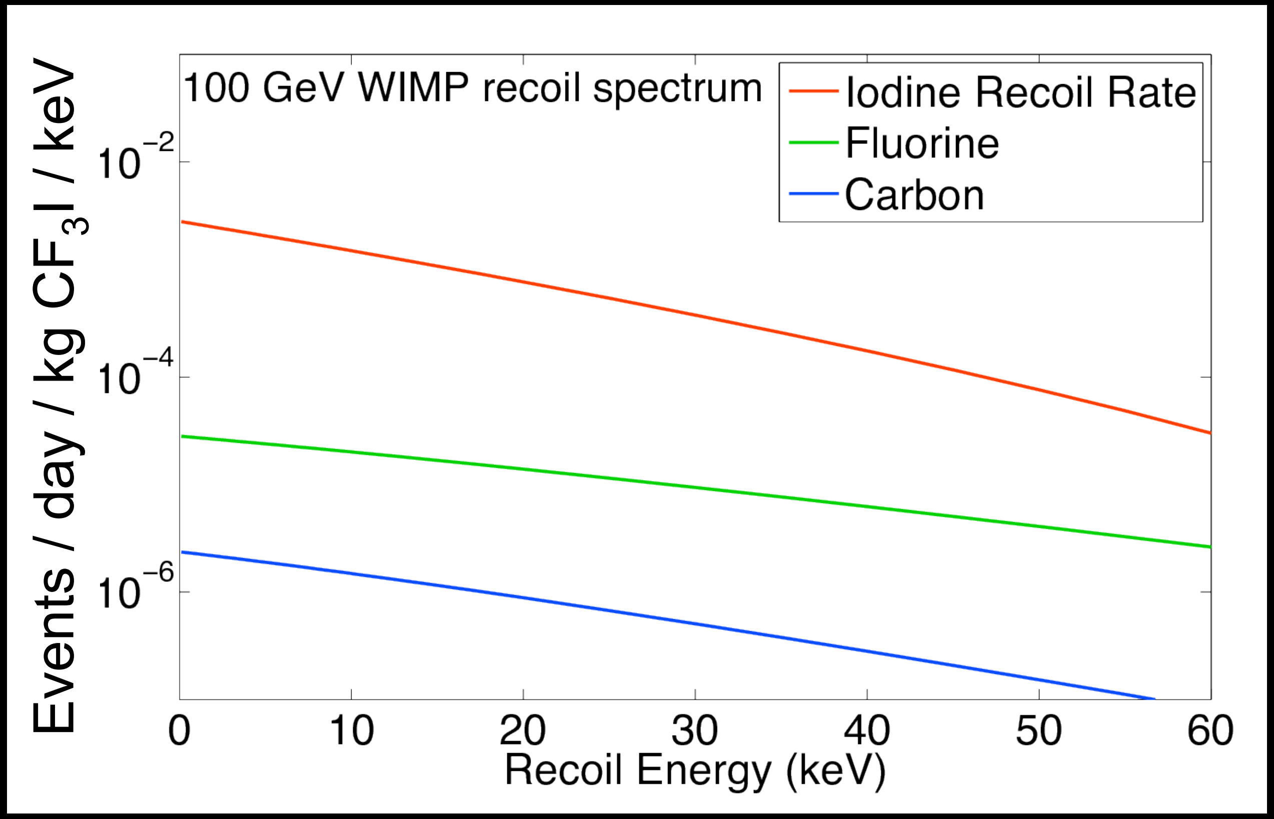

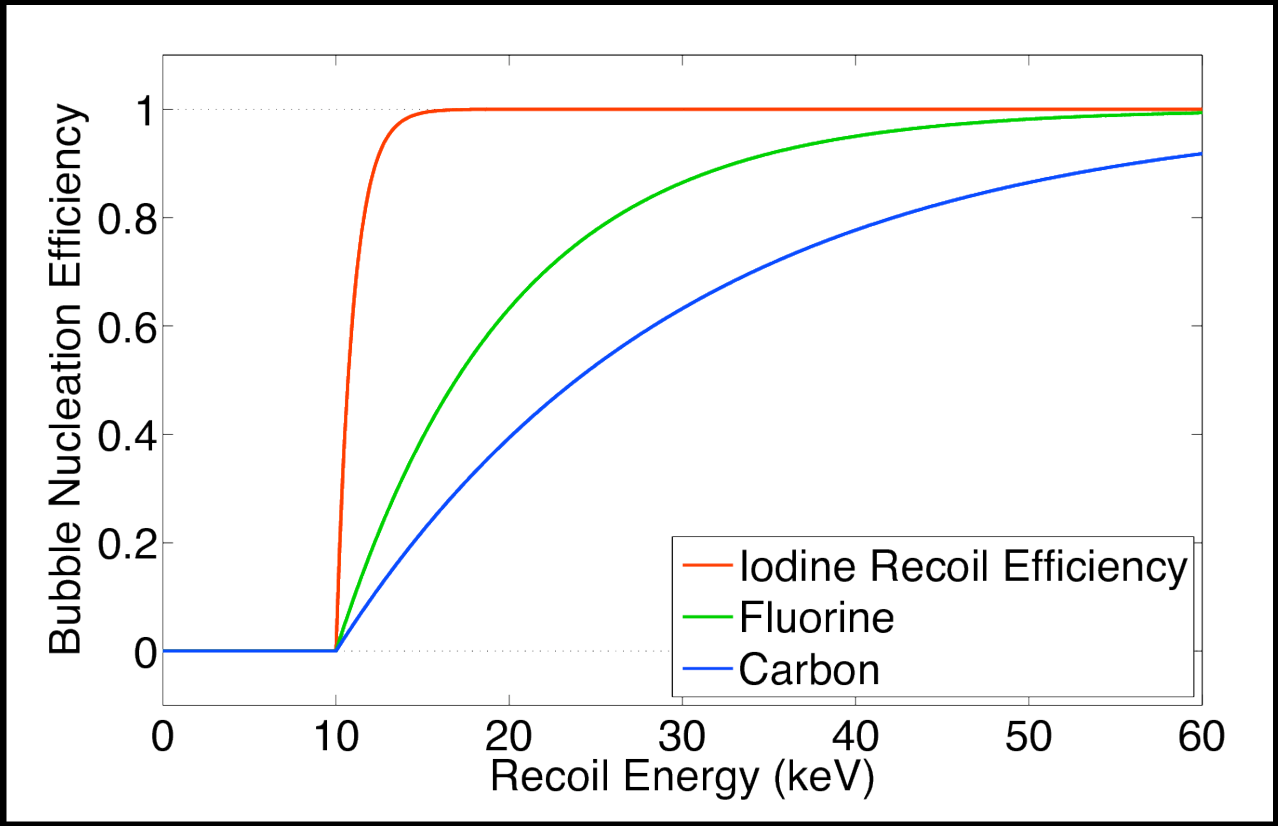

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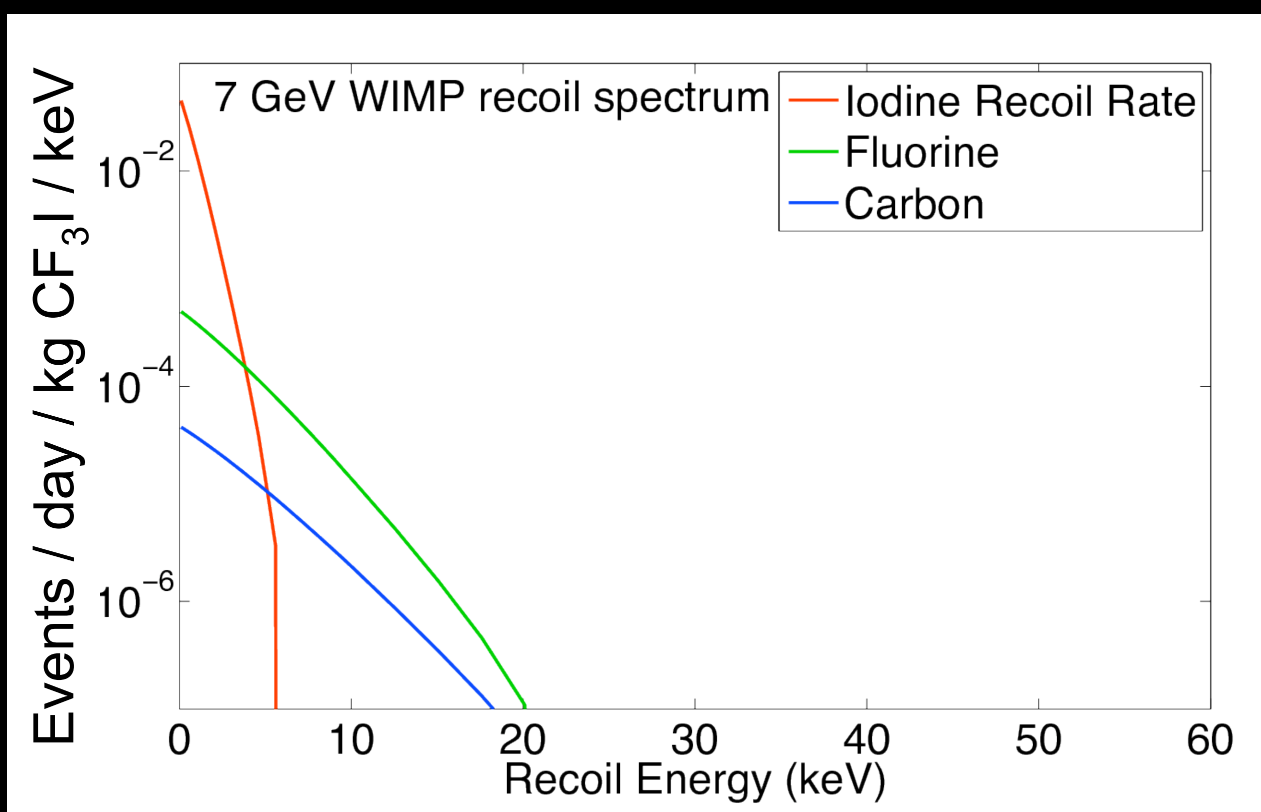

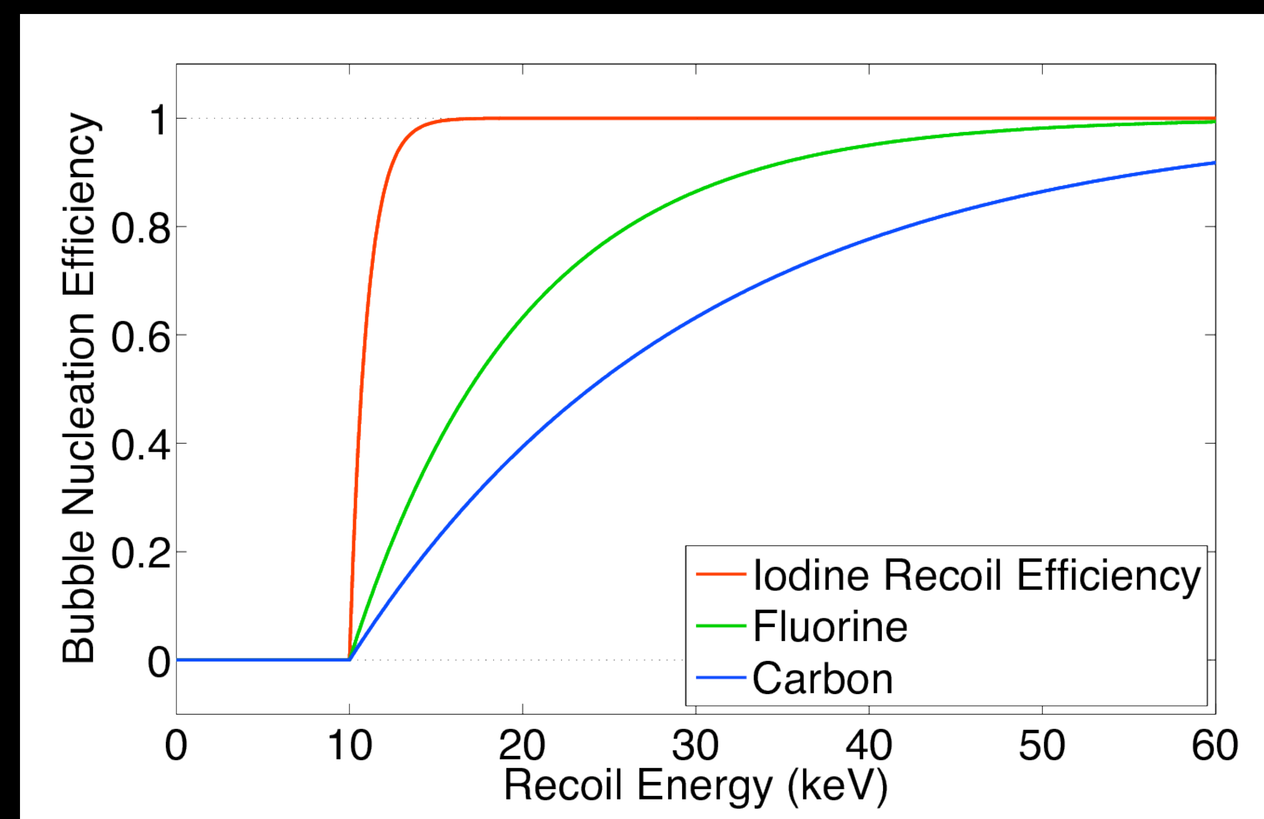

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Detour: Threshold and efficiency

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$$E_{th} = \boxed{4\pi r_c^2 \left(\sigma - T\frac{\partial \sigma}{\partial T}\right)} + \frac{4}{3}\pi r_c^3 \rho_v h$$

Surface energy

Latent heat

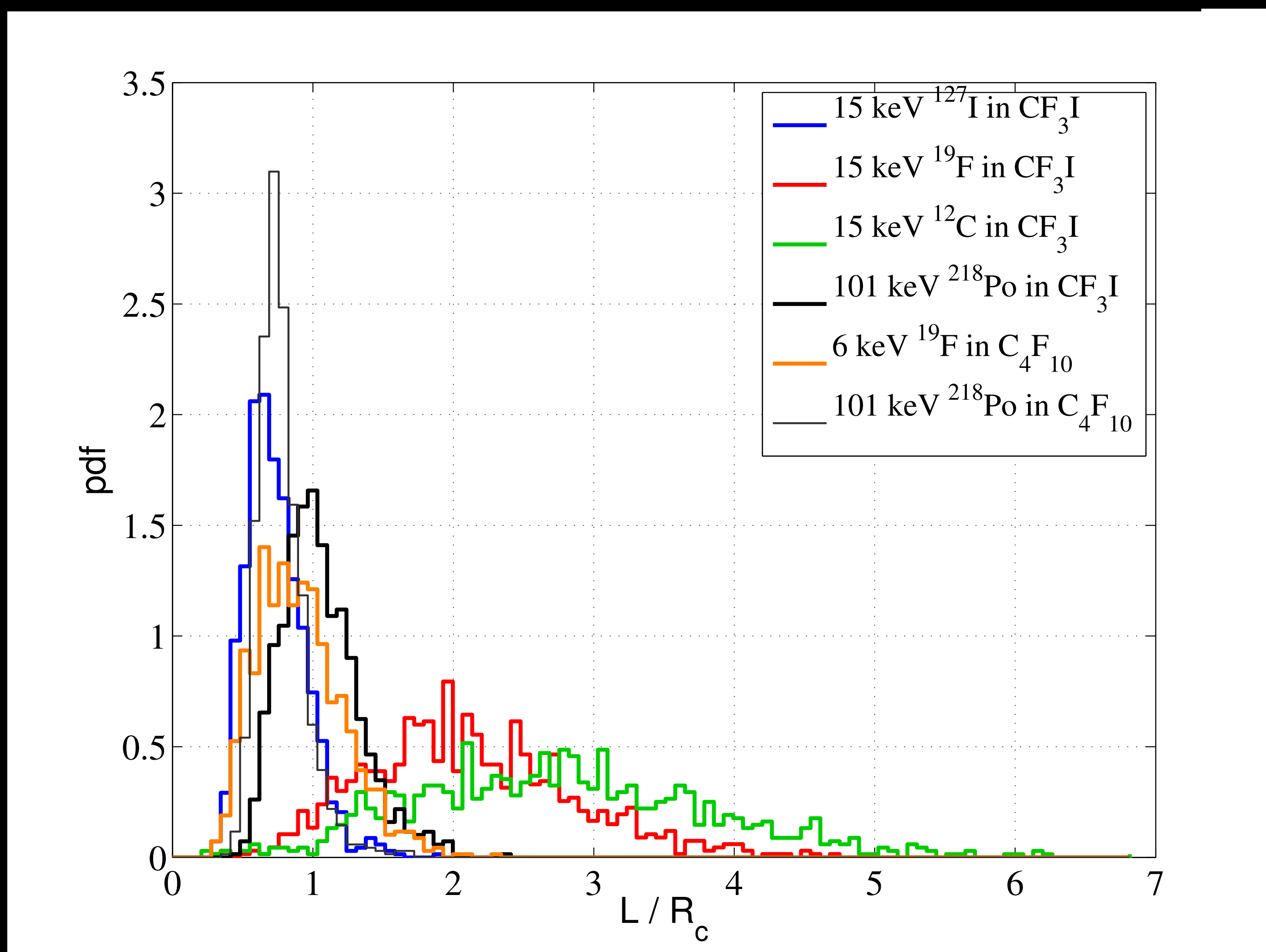
- Energy deposition E_{th} within length r_c will nucleate a bubble (Hot Spike model)

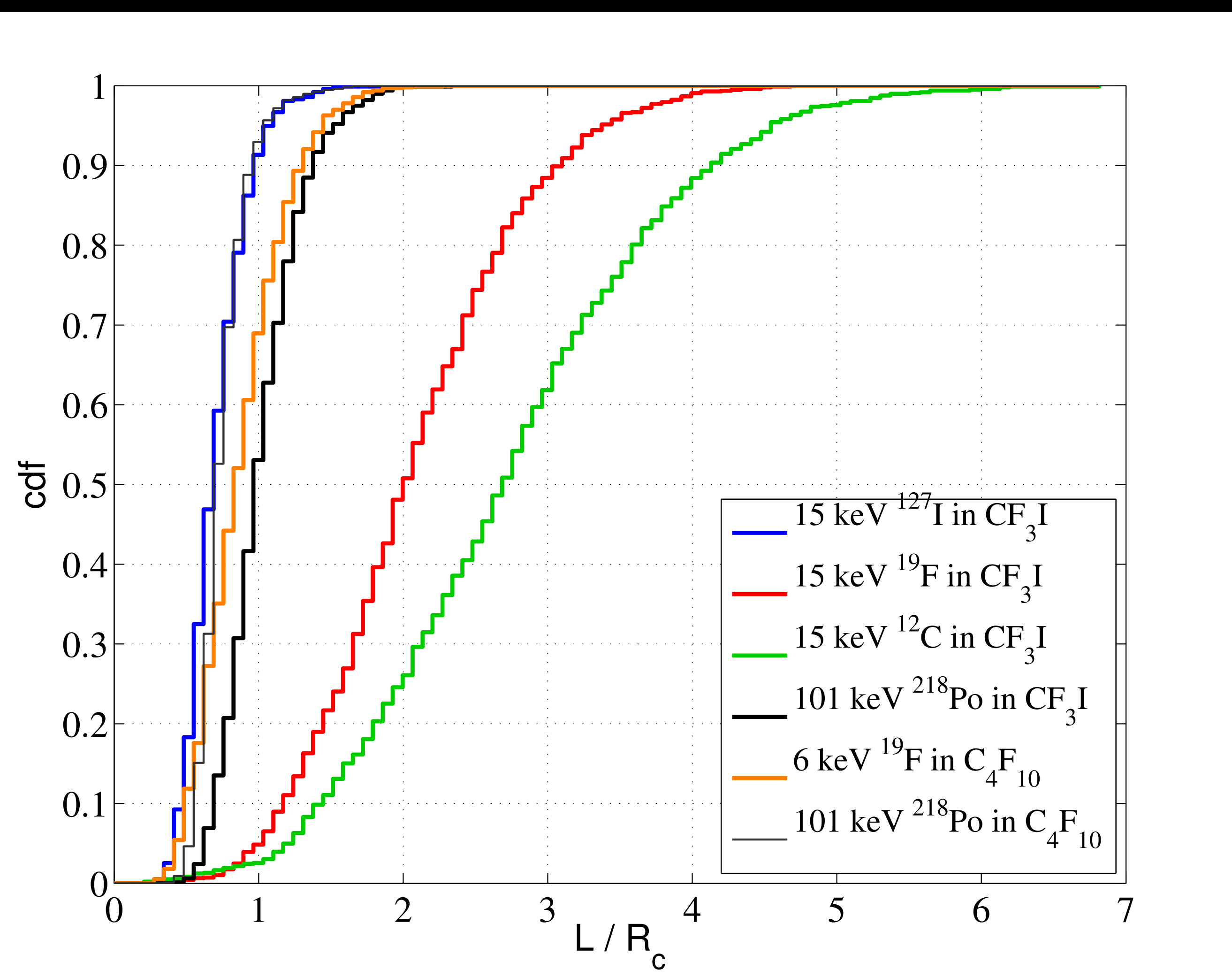
- Theory assumes a step function above threshold

  - Needs calibration

Detour: Threshold and efficiency

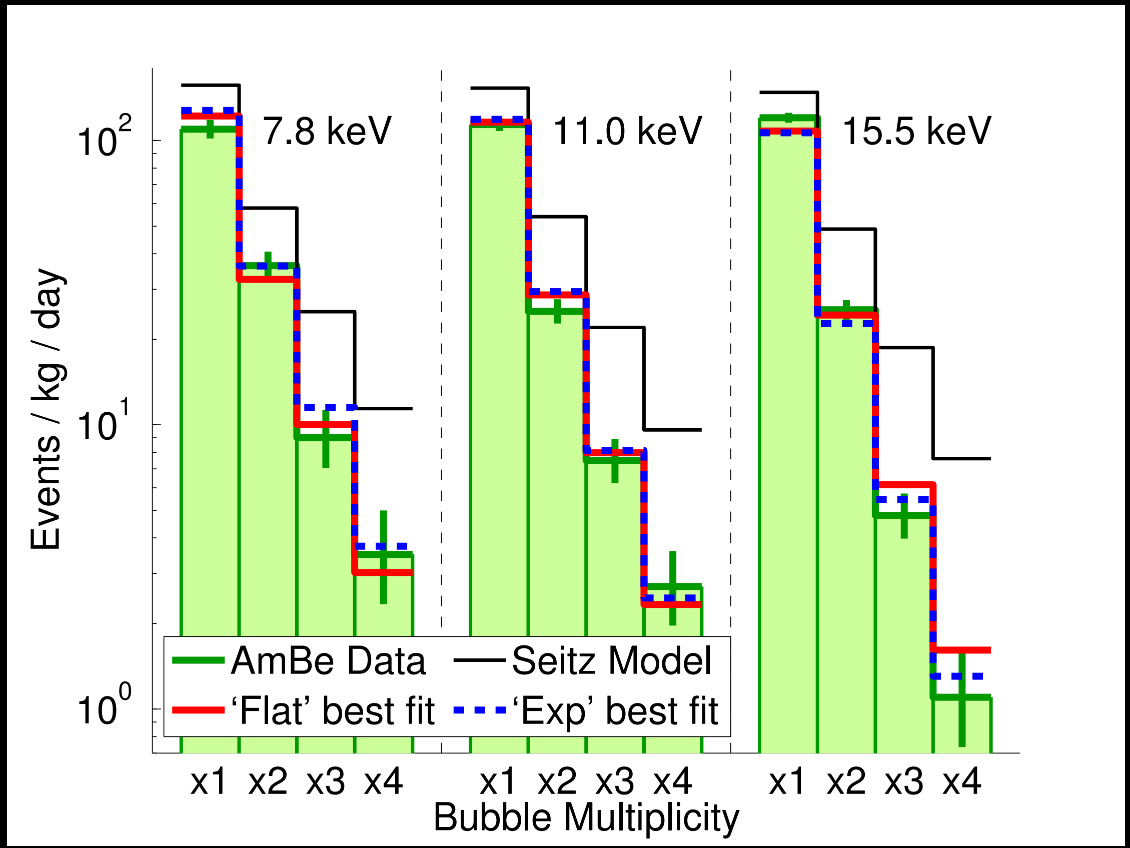
- Complicated by molecule, CF_3I
- Recall that the recoil track length L must be comparable to the bubble radius R_C

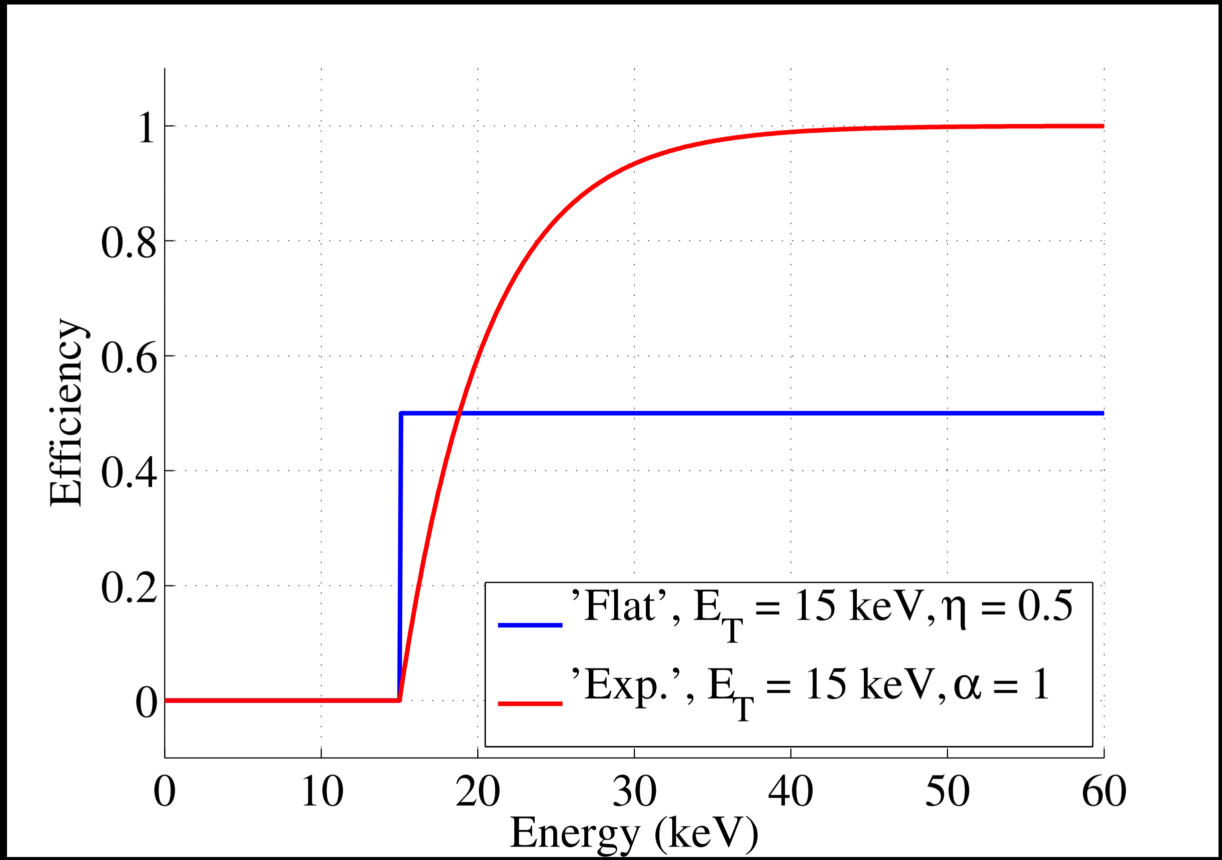




Carbon and fluorine

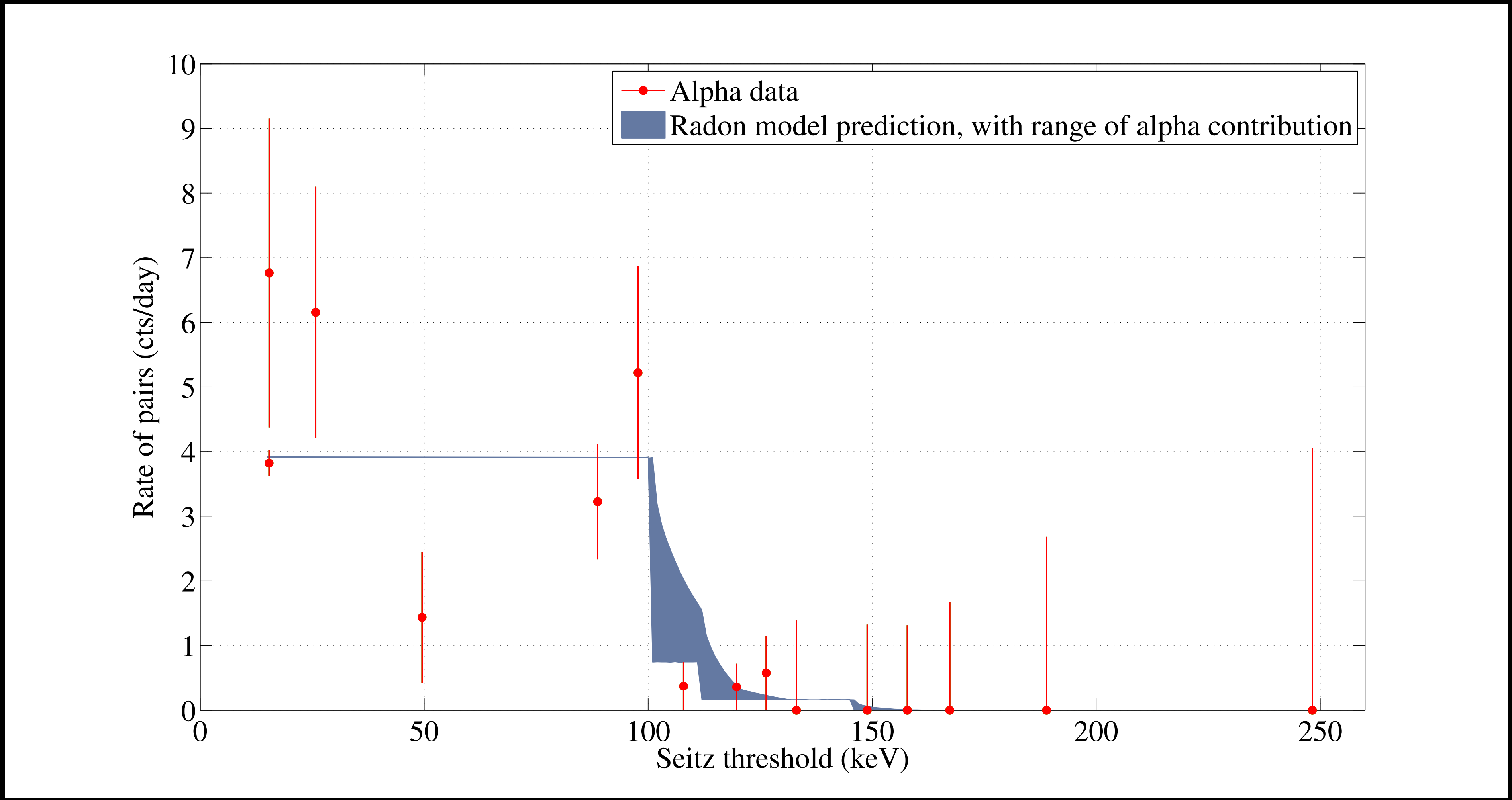
- Use neutron calibration sources at SNOLAB
- Compare MCNP-predicted rates of single, double, triple and quadruple bubble events with observation
- Data show a shortfall of events compared to simulation of the Seitz Model- i.e. the threshold is not a step function





What about iodine?

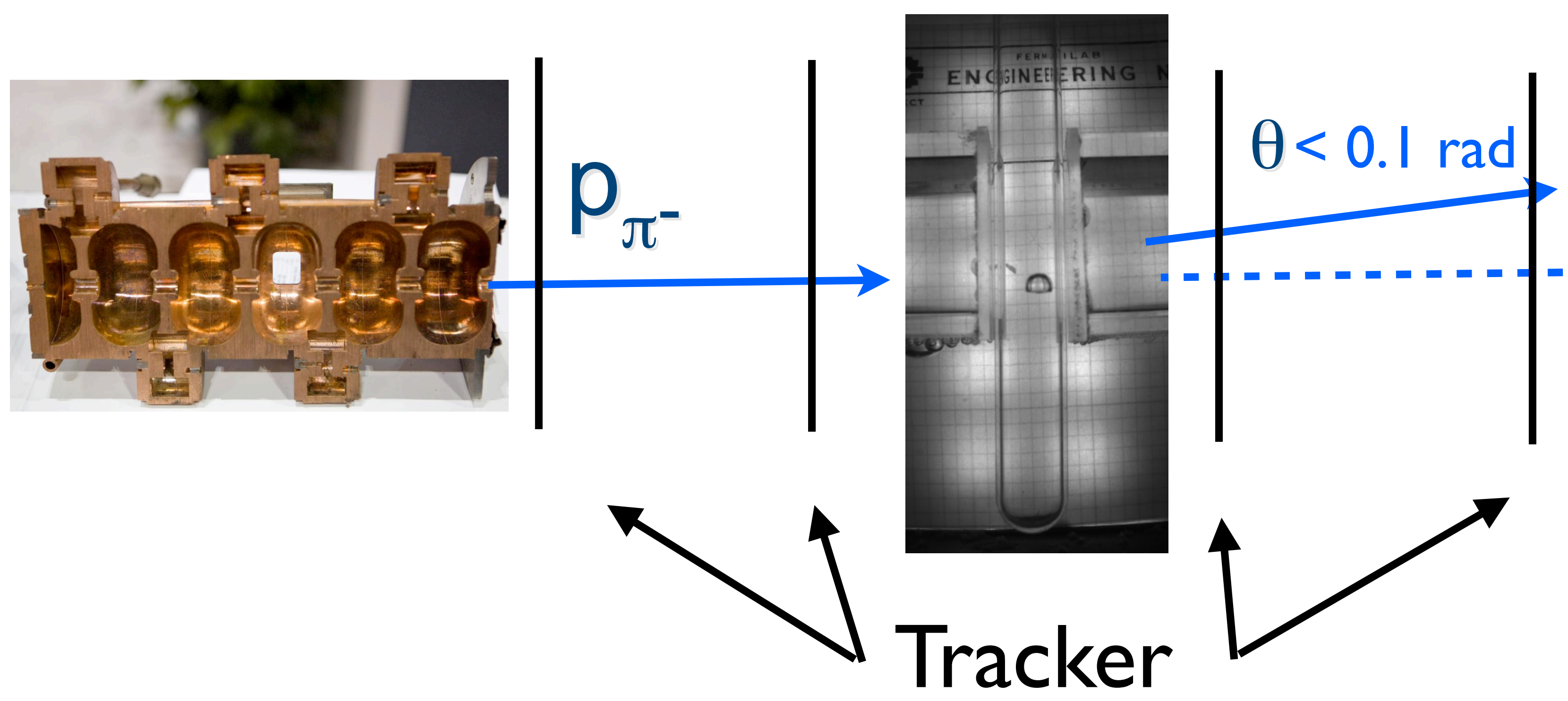
- Main sensitivity to spin independent dark matter from iodine
  - 85% of neutron source interactions are with C and F
- Heavy radon daughter nuclei are a proxy and are step-like



- We really need a direct calibration

COUPP Iodine Recoil Threshold Experiment

- Bubble chambers are insensitive to MIPs
  - Elastic scattering of charged particles can be tracked with very high precision

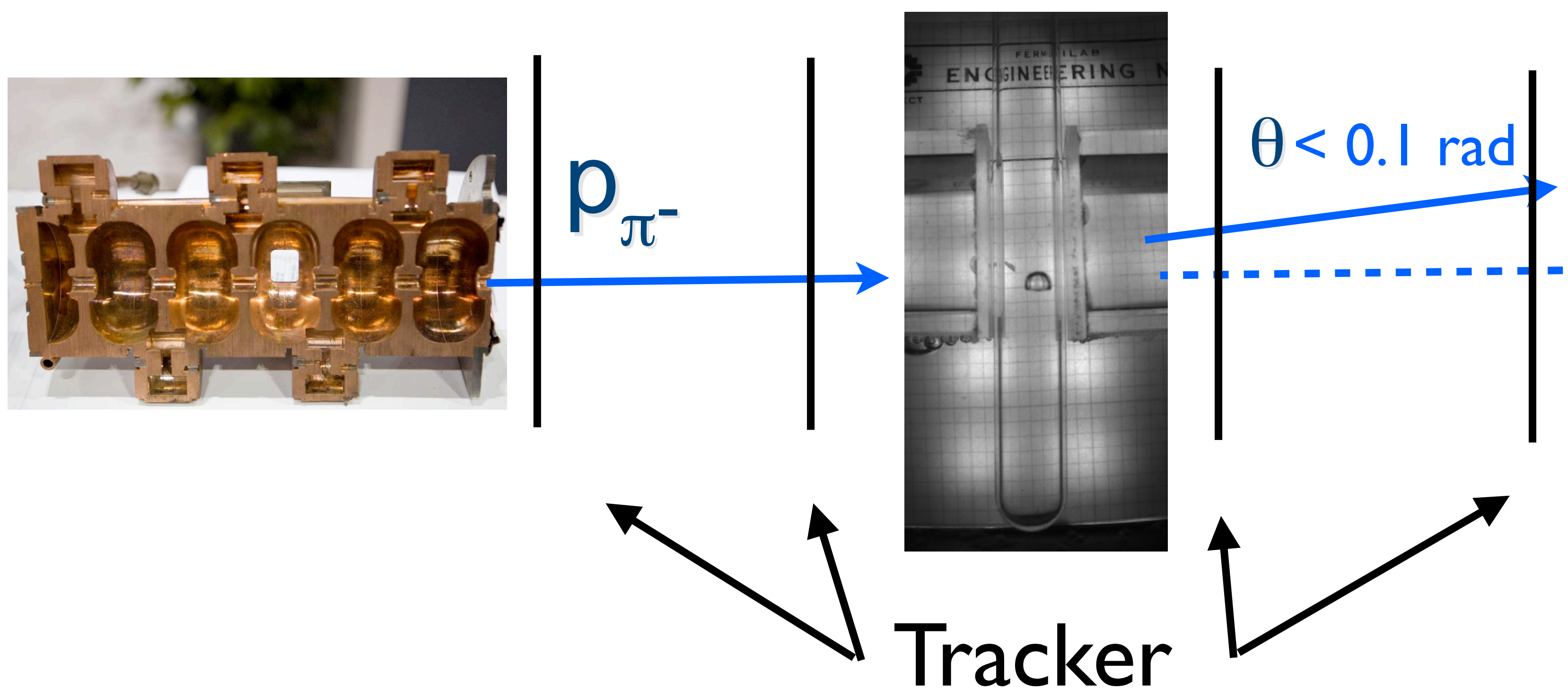


$$T = E_{recoil} = \frac{(p\theta)^2}{2m_r}$$

COUPP Iodine Recoil Threshold Experiment

- Provides event by event energy information bubble chambers normally can't provide

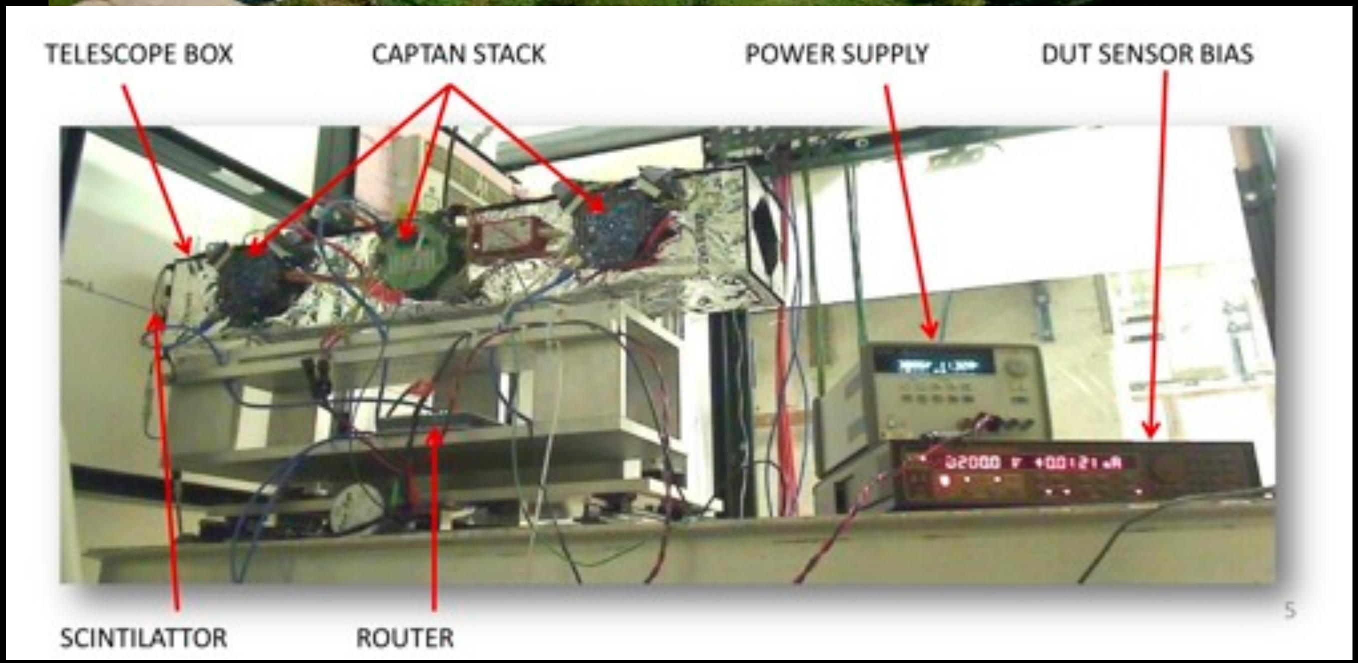
- 75% of elastic scattering events with 12 GeV pions at energies relevant to dark matter involve iodine

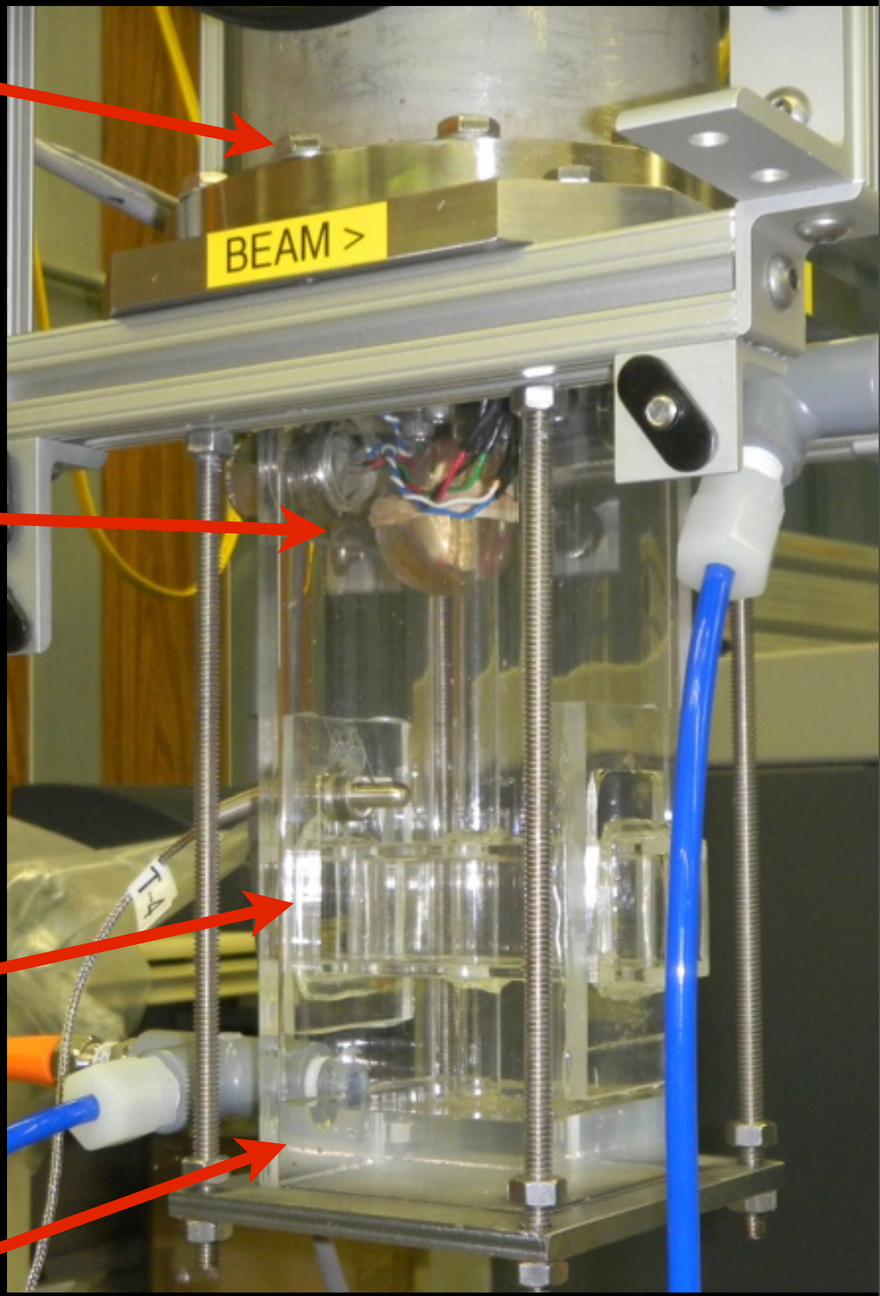


$$T = E_{recoil} = \frac{(p\theta)^2}{2m_r}$$

COUPP Iodine Recoil Threshold Experiment

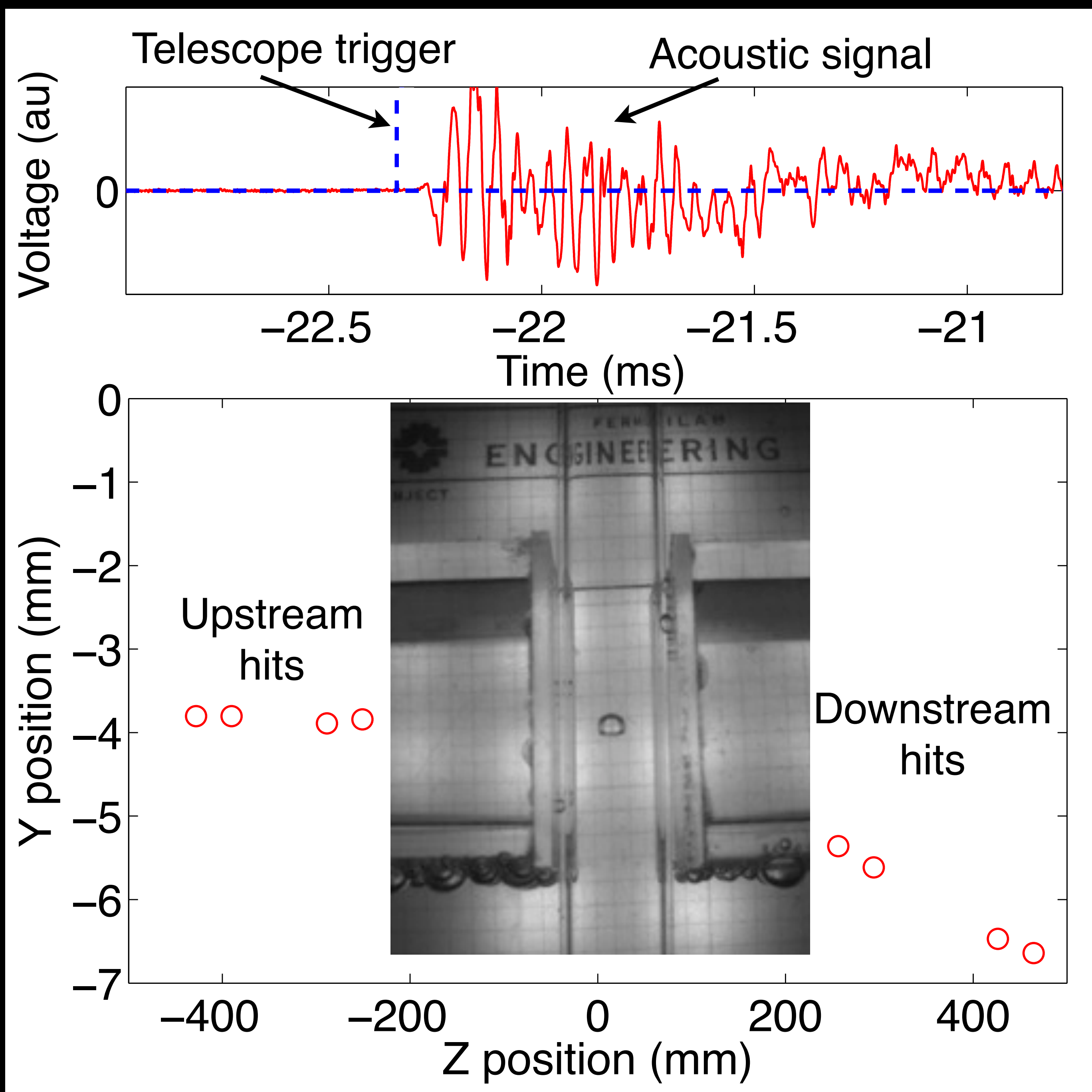
- Test beam at Fermilab with a silicon pixel telescope
- Designed a new test tube sized bubble chamber

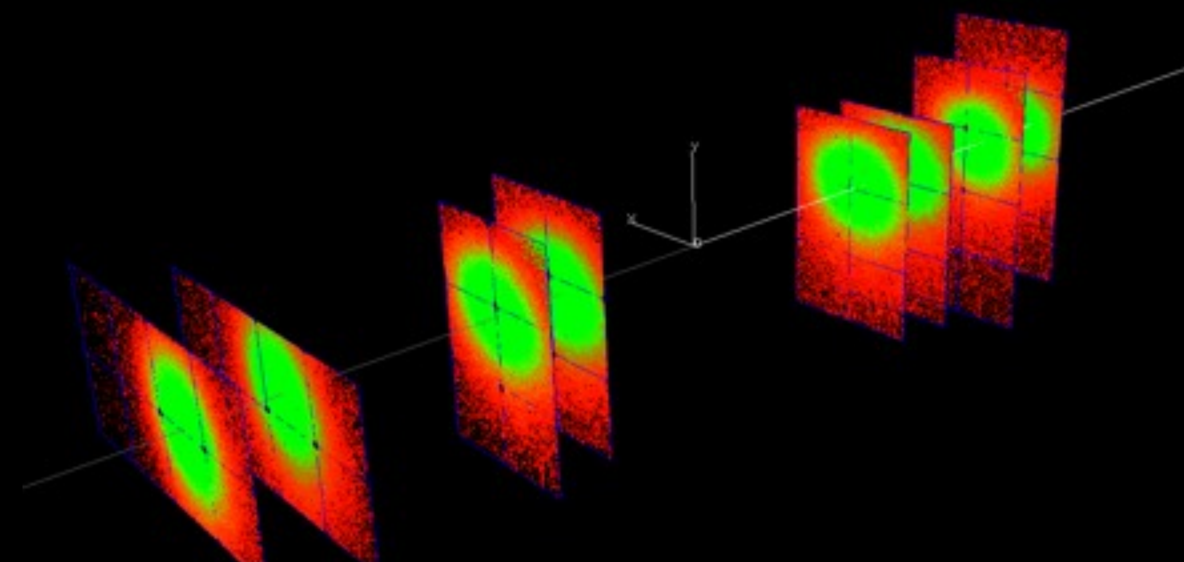


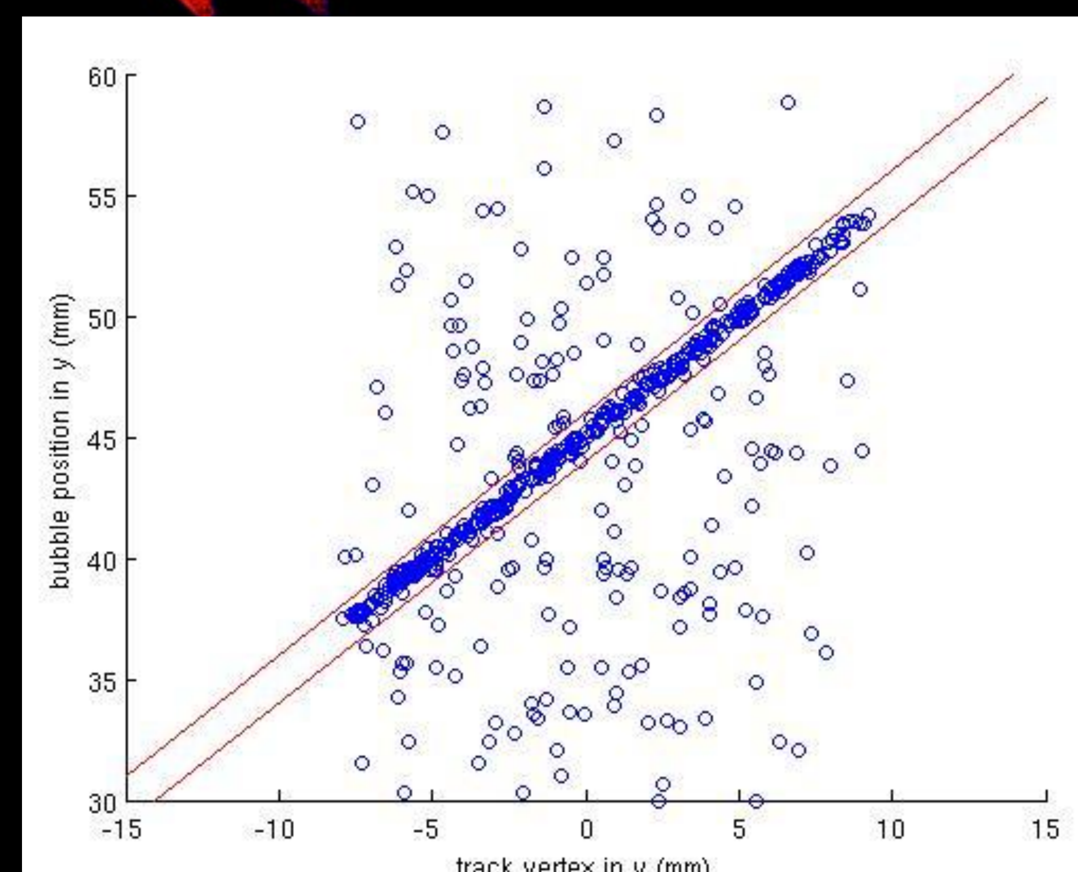


COUPP Iodine Recoil Threshold Experiment

- Beam run at Fermilab in March, 2012







COUPP Iodine Recoil Threshold Experiment

- Analysis shows that iodine threshold is very close to a step function at the predicted energy
  - Limited by resolution (MCS) and statistics